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A Review of Distribution System Monitoring Strategies under the Total Coliform Rule

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Background and Disclaimer

The USEPA is revising the Total Coliform Rule (TCR) and is considering new possible distribution system requirements as part of these revisions. As part of this process, the USEPA is publishing a series of issue papers to present available information on topics relevant to possible TCR revisions. This paper was developed as part of that effort.

The objectives of the issue papers are to review the available data, information and research regarding the potential public health risks associated with the distribution system issues, and where relevant identify areas in which additional research may be warranted. The issue papers will serve as background material for EPA, expert and stakeholder discussions. The papers only present available information and do not represent Agency policy. Some of the papers were prepared by parties outside of EPA; EPA does not endorse those papers, but is providing them for information and review.

Additional Information

The paper is available at the TCR web site at:

http://www.epa.gov/safewater/disinfection/tcr/regulation_revisions.html

Questions or comments regarding this paper may be directed to **TCR@epa.gov.**

Table of Contents

A Review of Distribution System Monitoring Strategies Under the Total Coliform Rule

Overview

Nature and Purpose of the Paper

This document summarizes existing information, literature, and research on distribution system compliance monitoring strategies for the Total Coliform Rule (TCR). The TCR requires all Public Water Systems (PWSs) to monitor for the presence of total coliforms and fecal coliforms or *E. coli* in the distribution system as an indicator of effectiveness of treatment and the vulnerability of a system to fecal contamination (54 Federal Register 27544, June 29, 1989). The focus of this white paper is on the design of coliform monitoring strategies (monitoring objectives, sampling plan design, analytical design, and statistical methods).

Separate white papers address the usefulness of total coliform as an indicator parameter, the TCR compliance history of water systems, and the potential applicability of Hazard Analysis Critical Control Point methodology in monitoring and controlling indicator organisms or pathogens in drinking water.

Regulatory Objectives of the TCR

The specific regulatory objectives of the 1989 TCR are fundamental to understanding the origins of water system monitoring practice under the TCR and to assess the effectiveness of existing monitoring strategies in meeting the regulatory objectives. The preamble to the proposed TCR describes the purpose of monitoring total coliforms: to evaluate the effectiveness of treatment, to determine the integrity of the distribution system, and to signal the possible presence of fecal contamination (USEPA, 1987). To meet these objectives the monitoring program must consider the three potential sources of microorganisms in distribution systems:

1. Microorganisms that pass through treatment,

2. Microorganisms that enter the system from the outside via means other than the treatment process (distribution system intrusion/contamination) or

3. Microorganisms multiplying within the distribution system, either in the bulk fluid or associated with deposits or biofilms.

This in turn requires understanding the importance of these pathways for coliform entry.

Monitoring Strategies

To evaluate TCR monitoring strategies, individual consideration of the components of the strategy is useful. Monitoring strategies consist of monitoring objectives linked to appropriate sampling designs, analytical designs, and statistical methods. Thus, more specific TCR monitoring objectives might be restated as follows:

1. Process Control: Monitor the effectiveness of the treatment process by determining whether coliforms are present in water entering the distribution system.

2. Characterizing System Reliability: Characterize the integrity of the distribution system by determining whether total coliforms, ubiquitous in the environment, are finding pathways to enter the distribution system or are persisting within the system (e.g., within biofilms or stagnant zones of storage tanks).

3. Contaminant Detection and Investigation: Detect fecal contamination (by analyzing for the presence of fecal coliforms or *E. coli* wherever total coliforms are found); use repeat sample information to aid in investigation and control of problem.

Sampling Plan Design

The dispersion of coliforms bears discussion because of its potential effect on the design of monitoring strategies and its implications for the sample volume and repeat sampling requirements of the existing TCR. Pipes and Christian demonstrated that coliforms were not randomly or uniformly dispersed in these water distribution systems. They showed that coliform count data could be fitted to either the truncated lognormal or the negative binomial distribution. Other researchers reported similar findings. Pipes and Christian also found that the variance of the counts was much greater than the mean.

Pipes and Christian summarized the challenge of TCR sampling plan design as follows:

> "It would be impossible to assure the microbial safety of every drop of water provided by a water system. For a 1 MGD system, there are 37,800,000 potential 100 mL samples per day or 1.34x10EE9 samples per month. The fraction of water that is tested for total coliforms is extremely small."

Allen, Clancy, and Rice (2001) argued for increased emphasis on monitoring indicator parameters for process control purposes, compared to direct pathogen monitoring, as a more appropriate means of protecting public health.

Speight and DiGiano (2004) utilized modeling and statistical techniques to assess the adequacy of distribution system sampling, and numerous other researchers have applied modeling tools to the task of developing monitoring plans.

Sample Location

The TCR specifies the total number of samples per month, but as noted above, the actual sample plan is determined by the utility and approved by the state. Consequently, sampling strategies vary nationally with respect to specific sample site requirements, the placement of sample sites, and the frequency of sampling at any one site.

Narasimhan (2003) surveyed current state policies regarding TCR sample collection and location selection. Narasimham found variation from state-to-state in the types of sites used for sampling. For example, with regard to sampling of storage facilities, the authors found that sampling practices range from collecting samples at each tank to no samples being taken in the

vicinity of tanks. Also, sample plans including consumer taps, dedicated sampling stations, and combinations of the two are acceptable depending on the individual state and circumstances.

The sampling protocol also varies among the states. Some states require systems to have exactly the same number of sampling locations as their required number of samples, and to collect one sample per month from each site. Other systems must identify a large pool of sample sites and rotate among the sites either randomly or based on a fixed schedule. Other systems identified fewer sites than the number of required samples and collect samples more frequently than once per month from the identified sites.

Each of these sampling strategies has advantages and disadvantages. Fixed sampling points provide more uniform information and a more reliable history of water quality. The second approach includes gathering observations at more (and presumably more geographically diverse) sites within the distribution system over time. However, each individual site is visited very infrequently; so the likelihood of capturing coliform positives due to site-specific factors may be reduced. Approaches that reduce the number of sample locations offers a greater ability to evaluate trends in water quality at each site, since data are collected more frequently at each site. Also, systems with a more limited number of sites may be able to better to reduce false positive and false negative samples by achieving better control of the environment at that sample location.

Also, by specifying (or excluding) particular sample locations, such as in water storage reservoirs, the primacy agency is biasing the TCR sample. Wong et al. (2005) demonstrates that sampling for total chlorine, free chlorine, nitrate, free ammonia, HPC, pH, and temperature can be very useful for managing reservoirs and as a component of a nitrification plan. Wong's use of reservoir monitoring to proactively manage nitrification illustrates that reservoirs are more likely to be sample sites with high HPC levels. Such an intentional bias can be effective, but it must be coordinated with the remainder of the monitoring strategy, including the interpretation and actions taken based on the observed results.

Sampling Protocols

Burlingame (1998) made recommendations for improved sampling practices to ensure that representative samples are collected, including sampling apparatus design, installation, and maintenance and flushing practices to discourage coliform growth in sampling lines. Dufresne et al. (1997) and Burlingame (1998) identified criteria for accepting or rejecting individual sampling stations for TCR compliance based on the potential for cross contamination. Studies by Ball et al. and Gueco, among others, showed improvements in TCR compliance after a system converted a large number of its sampling sites to dedicated sampling stations (Ball et al. 1999; Gueco, 1999).

Information Gaps

1. Tools are available to assist drinking water utilities and states to develop effective TCR monitoring strategies. The AwwaRF report, *Developing a Bacterial Sampling Plan*, is one document that provides a rational guideline for utilities of all sizes to design effective bacterial sampling plans (Narasimhan and Brereton, 2004). The

manual lays out a six-step approach to develop a distribution system bacterial sampling plan.

2. To determine how to use available tools to improve monitoring will require a clear understanding of the TCR monitoring objectives. Monitoring strategies can then be evaluated against those objectives and the practical realities of monitoring for rare events.

3. The statistics of monitoring rare events is critical to understanding the number of samples and allocation of samples for TCR sampling:

   - Hrudey and Rizak (2004) demonstrated that false-positive rates are quite high when monitoring rare events This has implications for the monitoring plan, analytical method performance requirements, and the actions required based on observed positives.

   - Pipes (1988) demonstrated that stratified, random sampling could be applied to water distribution systems but more recent research bears consideration and may lead to an alternative monitoring design.

4. Employing dedicated sampling stations or other means to reduce environmental contamination associated with the sample tap can substantially reduce noise observed in TCR monitoring.

5. There are significant opportunities for research that would refine the issues described in this report:

   - What are the relative contributions and absolute concentrations of infectious pathogens in tap water resulting from treatment plant pass-through, loss of integrity in the distribution system piping, biofilm development, backflow events, and on-premise plumbing? Which specific pathogens are occurring as a result of each of these potential sources? How effectively does the monitoring strategy identify the conditions when these pathogens are likely to be introduced to finished drinking water?

   - What factors are the most significant determinants of coliform occurrence distribution in public water system distribution systems? What practical indicators can be used to identify when individual public water systems should target particular determining factors to improve distribution system management?

   - Recognizing that the TCR's total coliform-*E. coli*-chlorine residual monitoring strategy is imperfect, could a more effective and efficient monitoring strategy be developed using another suite of indicators?

   - Can analytical methods for coliform bacteria, particularly *E. coli*, be improved to facilitate the current monitoring strategy by improving

holding times, reducing susceptibility to elevated temperatures during holding times, or increasing sample volume?

- Are there implementation training strategies that consistently achieve reductions in monitoring and reporting violations by systems?

A Review of Distribution System Monitoring Strategies Under the Total Coliform Rule

1.0 Introduction

This document summarizes existing information, literature, and research on distribution system compliance monitoring strategies for the Total Coliform Rule (TCR). The TCR requires all public water systems (PWSs) to monitor for the presence of total coliforms and fecal coliforms or *Escherichia coli* in the distribution system as an indicator of the effectiveness of treatment and the vulnerability of a system to fecal contamination (54 Federal Register 27544, June 29, 1989). The focus of this white paper is on the design of coliform monitoring strategies (monitoring objectives, sampling plan design, analytical design, and statistical methods).

This white paper does not address coliform monitoring for security purposes. Separate white papers address the usefulness of total coliform as an indicator parameter, the TCR compliance history of water systems, and the potential applicability of risk management methodologies, such as the Hazard Analysis Critical Control Point (HACCP) methodology, in monitoring and controlling indicator organisms or pathogens in drinking water. It is expected that some overlapping themes may emerge between this white paper and the other documents.

This white paper is organized as follows:

1.1 Summary of TCR Technical Requirements

Several aspects of the current TCR that will be discussed in this document are summarized in Table 1. Information in the table is presented for discussion purposes only and is not intended to be used for compliance decisions. Some information has been omitted for brevity. A complete copy of the codified rule is included in Appendix A.

Table 1. Summary of Existing TCR Requirements Addressed in this Document

Sampling Plan	Systems must collect routine total coliform samples at sites that are representative of water throughout the distribution system according to a written sample siting plan. These plans are subject to state review and revision.
Number and Frequency of Samples	The TCR requires systems to monitor for total coliforms at a frequency determined by the number of people served, ranging from 1 sample per month for systems serving fewer than 1,000 persons to 480 samples per month for systems serving over 3,960,000 persons. The system must collect samples at regular time intervals throughout the month, except that a system that uses only ground water (except ground water under the direct influence of surface water (GWUDI)), and serves 4,900 persons or fewer, may collect all required samples on a single day if they are taken from different sites.
Analytical Method, Sample Volume	The TCR considers the presence or absence of coliform bacteria in a sample rather than the bacterial density in a sample, using an approved method. The minimum sample size is 100 mL.
Repeat Samples	If any sample is total coliform-positive, the system must: test the positive culture for the presence of either fecal coliforms or *E. coli*; take one set of three or four repeat samples within 24 hours; and take at least five routine samples the next month of operation. The system must collect at least one repeat sample from the sampling tap where the original total coliform-positive sample was taken, and at least one repeat sample at a tap within five service connections upstream and at least one repeat sample at a tap within five service connections downstream of the original sampling site. If one or more repeat samples are total coliform-positive, the system must collect an additional set of repeat samples within 24 hours. The system must repeat this process until either total coliforms are not detected in one complete set of repeat samples or the system determines that the MCL for total coliforms has been exceeded and notifies the state. Results of all routine and repeat samples not invalidated by the state must be included in determining compliance with the MCL for total coliforms.
Use of Repeat and Special Purpose Samples in Calculation of MCL	Special purpose samples, such as those taken to determine whether disinfection practices are sufficient following pipe placement, replacement, or repair, are not used in the MCL compliance calculation.
Unfiltered Surface Water and GWUDI Systems	Unfiltered surface water and GWUDI systems must collect at least 1 sample near the first service connection each day the turbidity level of the source water exceeds 1 NTU. This sample must be analyzed for the presence of total coliforms. Sample results from this coliform monitoring must be included in determining compliance with the MCL for total coliforms.
Small Protected Groundwater Systems	Protected groundwater systems serving fewer than 1,000 people may reduce their sampling frequency under certain circumstances, with state approval.
Non-Community Systems	Monitoring frequencies may be reduced under specific circumstances that apply to certain non-community systems.
Sanitary Surveys	PWSs serving fewer than 4,100 persons must undergo a sanitary survey at least every 5 years (every 10 years for a noncommunity system using only protected and disinfected groundwater). The state must review the results and determine if the existing monitoring frequency is adequate.

1.2 Regulatory Objectives of the TCR

The specific regulatory objectives of the 1989 TCR are fundamental to understanding the origins of water system monitoring practice under the TCR and to assess the effectiveness of existing monitoring strategies in meeting the regulatory objectives. For decades, U.S. public health personnel have relied on enteric bacterial indicator microorganisms (predominantly "coliforms") as the primary means to detect the possible presence of microbial contamination of drinking water from human waste (National Research Council, 2004; USEPA, 1987). The 1989 TCR evolved from the coliform monitoring provisions of the 1975 National Interim Primary Drinking Water Regulations and its predecessor regulation, the U.S. Public Health Service's 1962 Federal Drinking Water Standards, which was in turn based upon federal drinking water standards established in 1914 (Clark et al. 2004). The TCR was proposed in 1987 and finalized in 1989.

According to the preamble to the proposed TCR, total coliforms are monitored to evaluate the effectiveness of treatment, to determine the integrity of the distribution system, and to signal the possible presence of fecal contamination (USEPA, 1987). Bacterial monitoring contributes to meeting these objectives but, as required by the TCR, is not adequate to assure that they are met. The effectiveness of treatment is determined by frequent or continuous measurement of turbidity and the disinfectant residual in the treated water. The stability of the treatment process is very important and there is a need for real time evaluation of its effectiveness. Compliance with the TCR is only one of several programs that a water utility needs to assure microbiological safety of the water.

The proposed rule put forth the concept of a monthly MCL to warn of acute health risk and a long-term MCL to characterize the consistency of the quality of the drinking water over a 12-month period or longer. The primary purpose of the long-term MCL was to ensure the reliability of the water system over time and water quality throughout the distribution system. EPA defined "reasonably safe" water for purposes of the long-term MCL as demonstrating 95 percent confidence that the fraction of water with coliforms present is less than 10 percent, noting that this definition was consistent with the recommendations of a 1981 workshop sponsored by EPA's Office of Drinking Water in conjunction with the American Society for Microbiology. EPA considered that acute contamination would be indicated by several coliform-positive samples closely spaced in time, and, therefore, proposed a limit of coliform-positive samples per month of five percent.

The final TCR modified the acute and long-term MCL as presented in the proposed rule. Under the current regulation, an acute MCL violation is one in which fecal coliforms or *E. coli* are present in either initial or repeat samples or both. The long-term concept evolved into the total coliform MCL: no more than 5.0 percent of the monthly samples may be coliform positive (for systems analyzing at least 40 samples per month) or no more than one sample per month may be total coliform-positive (for systems analyzing fewer than 40 samples per month). No statistical justification was made for the presumed "safe" water concept of having 95% confidence that less than 10% of the water is contaminated with coliform bacteria. In addition, no scientific reason has been described for evaluating water quality at time intervals of calendar months.

Specific monitoring provisions for the final 1989 TCR were developed following a public comment process. It is clear from the transcript of one professional discussion (recorded in 1988) that many of the issues that might be considered in revision of the 1989 TCR were actively considered during the discussions leading up to the 1989 rule (Geldreich, 1988). Three topics discussed during the TCR development are integrally related to the current discussion of the objectives of TCR monitoring plans and are discussed in greater detail: monitoring frequency, sampling sites, and repeat samples.

1.2.1 Monitoring Frequency

The final TCR established public water service population as the basis for setting monitoring frequency. Alternative approaches considered in the proposed TCR are summarized in Table 2.

Table 2. Monitoring Frequency Considerations

Proposed Criterion for Monitoring Frequency	Considerations
Population served	As the population served increases, so does size and complexity of system and the potential for distribution network contamination by back-siphonage and cross connections. Also, the larger the population served, the greater the number of persons at risk when water treatment is defective.
Number of service connections (excluding fire hydrants)	Large populations of multi-family residences or workplace sites are not reflected in the number of service connections.
Total length of the distribution pipe network	Increased length of pipe network reflects increased risk of contamination from residential and commercial service connections and by ground disturbance in the area of construction projects. Where local topography requires long distribution lines to reach small clusters of homes, this approach is misleading.
Volume of water provided (e.g., by different pressure zones of a system)	Public water systems know, with some accuracy, the water demand of different zones of the distribution system. A significant portion of water demand may relate to industrial use and lawn watering, rather than to drinking water consumption.

Upon establishing population as the criterion for monitoring frequency, EPA had to determine what number of samples would be required to be collected by different population categories. The numbers used in the interim regulations (also population-based) were based on the 1962 regulations, which were founded upon an unpublished study of sampling practices in New York state that reflected what was financially and technically attainable at that time. This monitoring frequency was only slightly modified for the final 1989 TCR to simplify the number of population categories (52 Federal Register 42224, 54 Federal Register 27544). Table 3 shows the required monitoring frequency for the TCR.

The number of samples that small systems would be required to collect was the subject of various studies from which EPA concluded that most samples, even in a contaminated system, will be coliform-free, due to the uneven dispersion of coliforms, and therefore, a larger number of samples is necessary to detect contamination (52 Federal Register 42224; Pipes and Christian, 1982; Christian and Pipes, 1983; Pipes, 1983). Thus EPA proposed that small systems serving a population of 3,300 or fewer persons collect a minimum of five samples per month.

EPA restructured the monitoring approach in the final TCR in response to comments expressing concern about the monitoring burden. The final rule focuses on evaluating the severity and extent of any contamination problem by requiring increased repeat monitoring when a positive coliform is detected, while placing less emphasis on collecting many routine samples. This modification allows certain systems to collect fewer than five samples per month.

1.2.2 Sampling Sites

The interim regulations suggested, but did not specify, sampling throughout the water distribution system. EPA proposed to refine the interim regulatory requirement that "samples are to be taken at points representative of conditions within the distribution system" by "requiring systems to collect samples from at least three times the number of sites every year as the number of monthly samples required or the total number of service connections." In addition, EPA recommended, but did not require, that systems select new sampling sites every year. The intent of these provisions was to insure that the system would eventually collect samples from all major sections of the distribution system (54 Federal Register 27544). The rationale for this proposal was work by Pipes and Christian in 1982 that found that differences in the frequency of coliform occurrences could be substantial in different parts of a distribution system. The study also found that the variability did not increase with distance from the water source. EPA concluded that all parts of the system should be sampled eventually.

However, EPA dropped the proposed sampling location requirements after encountering significant opposition. Some commenters recommended that EPA allow all, or at least some, sampling sites, to be fixed to afford utilities the opportunity to maintain long-term records to detect trends at specific sites. Others were concerned that the proposed strategy would force systems to use private homes, with possible problems of access, especially for repeat samples (54 Federal Register 27544). EPA ultimately deci:ed to require systems to use a sample-siting plan acceptable to the state (May 6, 1988, notice).

> "Each system must develop and monitor according to a written sample siting plan, which is subject to state review and revision. The state must develop and implement a process which ensures the adequacy of the sample siting plan for each PWS in the state, including periodic review of each system's plan. For the vast majority of systems, EPA expects the state will conduct this periodic review as part of the periodic sanitary survey. The siting plan should ensure that the system will eventually detect contamination in any portion of the distribution system if it is present. While reviewing the siting plan, the state should also review the sample collection timing patterns for each system to determine whether the system should collect samples on a regular basis throughout the month, or whether it is acceptable to collect some or all required samples at the same time" (54 Federal Register 27544).

Table 3. Total Coliform Sampling Requirements, According to Population Served

Population served	Minimum number of routine samples per month
25 to 1,000	1
1,001 to 2,500	2
2,501 to 3,300	3
3,301 to 4,100	4
4,101 to 4,900	5
4,901 to 5,800	6
5,801 to 6,700	7
6,701 to 7,600	8
7,601 to 8,500	9
8,501 to 12,900	10
12,901 to 17,200	15
17,201 to 21,500	20
21,501 to 25,000	25
25,001 to 33,000	30
33,001 to 41,000	40
41,001 to 50,000	50
50,001 to 59,000	60
59,001 to 70,000	70
70,001 to 83,000	80
83,001 to 96,000	90
96,001 to 130,000	100
130,001 to 220,000	120
220,001 to 320,000	150
320,001 to 450,000	180
450,001 to 600,000	210
600,001 to 780,000	240
780,001 to 970,000	270
970,001 to 1,230,000	300
1,230,001 to 1,520,000	330
1,520,001 to 1,850,000	360
1,850,001 to 2,270,000	390
2,270,001 to 3,020,000	420
3,020,001 to 3,960,000	450
3,960,001 or more	480

1.2.3 Repeat Samples

EPA proposed collection of five repeat samples for every coliform-positive sample in its 1987 proposed rule, and that this set of samples be collected at the same service connection as the coliform-positive sample, except that some of the repeat samples may be taken at the next service connection "above or below". Furthermore, a system would be required to collect repeat samples at these locations until a set of five samples was coliform-negative or until an MCL was exceeded. In the final TCR, EPA reiterated that its intent in requiring collection of repeat samples was to encourage the investigation of the extent of coliform contamination and to determine if the degree of contamination jeopardizes the safety of the water, rather than to confirm a total-coliform-positive initial sample, which, it noted, cannot be done because coliforms are not distributed uniformly in the distribution system—the absence of total coliforms in a follow-up sample does not imply that coliforms were not present in the water represented by the initial sample.

In the final TCR, the repeat sampling requirements were modified to require only three repeat samples for larger systems collecting more than one routine sample per month: one at the same tap as the original coliform-positive sample, one at a tap within five service connections upstream and one at a tap within five service connections downstream of the original sampling site. Systems collecting only one sample or fewer per month would be required to collect four repeat samples and would be required to collect at least five routine samples the following month.

The primary rationale behind the minimum repeat sample requirements seems to have been to provide data to more immediately evaluate the safety of the water, based on EPA's statistical definition of "reasonably safe" referenced in the proposed TCR (95 percent confidence that the fraction of water with coliforms present is less than 10 percent). The upstream/downstream provision was intended to provide the system information as to whether the contamination is a non-distribution-system problem.

1.2.4 Research Needs

Research questions that have emerged concerning the objectives of the TCR may be summarized as follows:

- Why are there generally a large number of monitoring violations associated with the TCR, compared to other primary drinking water regulations? Does the large number of monitoring violations reflect that the rule is effective in protecting consumers from microbial risks (e.g., TCR monitoring minimizes the risk of consumers drinking water that is actually contaminated)? Does it imply an unnecessarily high water utility risk (e.g., water that is actually of acceptable quality is being deemed unacceptable)?

- What are the current operational objectives of coliform monitoring in the distribution system? Have these objectives differed from the three historical purposes of coliform monitoring?

- What evidence exists to measure the effectiveness of the strategies used by water systems in meeting the TCR's implied objectives?

- How well do the monitoring strategies employed by water systems support the TCR objectives? That is, how well do the sites and frequencies established in sample siting plans, the sampling practices used by systems, and the analytical tests used in TCR compliance support the TCR objectives?

- How effective has the upstream/downstream follow-up sampling provision been in aiding in the assessment of coliform occurrences?

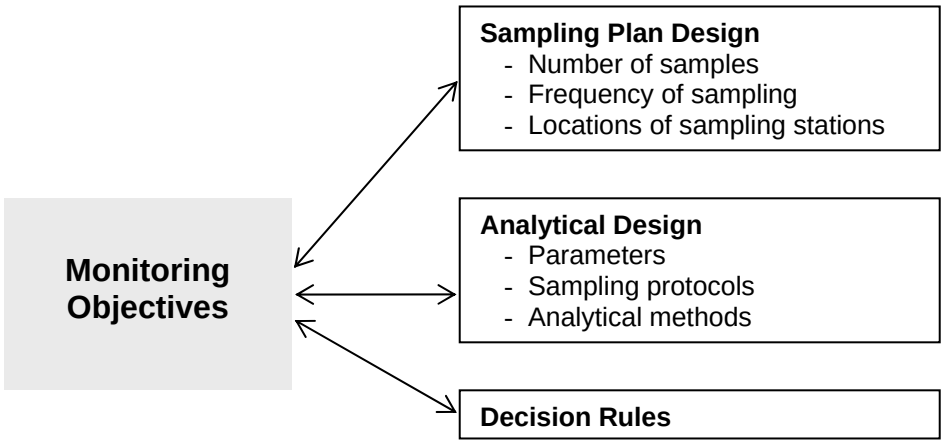
- With regard to monitoring total coliforms for purposes of process control, are typical monitoring programs structured to collect data frequently enough and at appropriate locations so that the coliform data can be used for immediate process-related decision making? If not, what is the appropriate structure of such a sampling program and how would it be implemented?

- With regard to monitoring total coliforms for purposes of system characterization, should sampling sites be chosen on the basis of system characteristics that are associated with intrusion, permeation, main breaks, disinfectant decay, etc., (such as pipe age, pipe materials, or low flow conditions)?

2.0 Overview of Monitoring Strategies

To evaluate TCR monitoring strategies, it is useful to consider, individually, several components that, taken together, constitute the strategies. Monitoring strategies consist of monitoring objectives linked to appropriate sampling designs, analytical designs, and decision rules. These components are depicted in Figure 1. The USEPA's *Guidance for the Data Quality Objectives Process* describes a systematic approach that integrates these components using a 7-step process as summarized in Table 4 (USEPA, 1994).

Figure 1. Monitoring Strategy Components



Source: EPA Guidance for the Data Quality Objectives Process

Table 4. Summary of the Data Quality Objectives Process (USEPA, 1994)

1	**State the Problem**	Concisely describe the problem to be studied. Review prior studies and existing information to gain a sufficient understanding to define the problem.
2	**Identify the Decision**	Identify what questions the study will attempt to resolve, and what actions may result.
3	**Identify Inputs to the Decision**	Identify the information that needs to be obtained and the measurements that need to be taken to resolve the decision statement.
4	**Define the Study Boundaries**	Specify the time periods and spatial area to which decisions will apply. Determine when and where data should be collected.
5	**Develop a Decision Rule**	Define the statistical parameter of interest, specify the action level, and integrate the previous DQO outputs into a single statement that describes the logical basis for choosing among alternative actions.
6	**Specify Tolerable Limits on Decision Errors**	Define the decision makers' tolerable decision error rates based on a consideration of the consequences of making an incorrect decision.
7	**Optimize the Design**	Evaluate information from the previous steps and generate alternative data collection designs. Choose the most resource-effective design that meets all DQOs.

In developing the TCR, EPA assumed a goal for reasonably safe water quality of 95 percent confidence that coliforms were present in less than 10 percent of the water. Assuming that this definition of reasonably safe water continues to be acceptable, the TCR monitoring strategies should test whether water meets this goal. *Maintaining Distribution System Water Quality* (AWWA, 1986), provided a straightforward description of the ideal strategy: "Establishing representative sampling points ensures that sampling results give an accurate indication of the bacteriological quality of the water supplied throughout the distribution system. Results of system sampling should show if there are quality changes in all or parts of the system and may point to the source of the problem." In practice, however, defining "representative sampling points" with regard to TCR monitoring is difficult for a number of reasons, which are discussed in subsequent sections of this white paper. Monitoring objectives and sampling plan design are discussed further in Sections 2 and 3, and analytical designs and decision rules are discussed in Section 4.

2.1 Distribution System Microbial Monitoring Objectives

AwwaRF's *Guidance Manual for Distribution System Monitoring* states that the critical first step in developing a monitoring strategy is to identify the objective of monitoring (Kirmeyer, et al., 2002). The authors suggested several possible objectives of distribution system monitoring, including regulations-driven monitoring aimed at rule compliance; public health protection; operations monitoring to optimize distribution system operations; maintenance-driven monitoring aimed at planning and conducting maintenance; monitoring to support capital improvements; and customer-related monitoring. The TCR "regulatory-driven" monitoring strategy takes place in the context of public water system operations. Examples of questions posed within the operations context are listed in Table 5.

Table 5. Operations Monitoring Objectives and Questions

Monitoring Objective	Example Question
Operations	What is the optimal operation of configurations to maintain water quality?
Maintenance-driven	Can monitoring anticipate and/or predict the onset of water quality deterioration?
Support for capital improvements	Do we need to replace the piping system?
Customer-related	What data can be collected to anticipate or prevent customer complaints?

The sampling plan design for these other monitoring needs may or may not align with the regulatory monitoring scheme, but to the extent to which the monitoring strategy meets multiple needs, then the more effective it will be for the public water system to implement.

Pipes and Christian (EPA R-805-637) stated that the objective of microbiological monitoring of a water distribution system is to provide a quantitative measure of the reliability of multiple barriers against the transmission of waterborne disease, rather than to assure the safety of the water. They clearly distinguished safety from reliability, noting that it is impractical to test any significant fraction of the water from a distribution system that will be consumed by humans to achieve the reasonable assurance of safety afforded by the absence of coliform bacteria in the samples.

Kirmeyer et al. (2002) suggested monitoring for coliforms to meet various objectives, including: baseline monitoring, management of water age, monitoring reservoir ingress and contamination, managing new construction and pipe replacement, and as part of flushing programs. For each of these purposes, the authors propose the type of monitoring sites (e.g., reservoir outlets, dead ends, or sites throughout the system) that should be selected.

Havelaar (1994) recommended including frequent monitoring of total coliforms and other parameters at critical control points to prevent system contamination from cross connections and storage facilities when applying the HACCP risk assessment approach to distribution systems.

EPA has stated that total coliforms are monitored under the TCR to evaluate the effectiveness of treatment, to determine the integrity of the distribution system, and to signal the possible presence of fecal contamination (USEPA, 1987). Thus, more specific TCR monitoring objectives might be restated as follows:

- Process Control: Monitor the effectiveness of the treatment process by determining whether coliforms are present in water entering the distribution system.

- Characterizing System Reliability: Characterize the integrity of the distribution system by determining whether total coliforms, ubiquitous in the environment, are finding pathways to enter the distribution system or are persisting within the system (e.g., within biofilms or stagnant zones of storage tanks).

- Contaminant Detection and Investigation: Detect fecal contamination (by analyzing for the presence of fecal coliforms or *E. coli* wherever total coliforms are found); use repeat sample information to aid in investigation and control of problems.

Kirmeyer et al. (2002) described four organizational categories that are also important to the data collection strategy. Those categories are:

1. Management, for which the key data uses are overall administration and financing of the water system.

2. Maintenance, which needs information associated with the sanitary conditions of the system related to maintenance, repair, and cleaning.

3. Operations, which is primarily concerned with the hydraulic operation of the system, but is also responsible for identifying and responding to complaints, contamination, and factors that affect ongoing regulatory compliance.

4. Engineering, which requires data to plan for the future of the organization, both with respect to capital and operational decisions; frequently this function encompasses research on water quality impacts.

Recently, the engineering organizational category has had to address concerns regarding identifying analytical tools, sampling strategies, and algorithms to diagnosis distribution system security breaches. At present it remains a separate, parallel monitoring consideration. Developing a contaminant warning system to identify deliberate contamination of distribution systems faces a number of implementation hurdles. These challenges are reflected in the report of an expert workgroup on contaminant warning systems that was organized by AWWA in 2005 (Roberson and Morley, 2005):

1. Lack of a clear objective for contaminant warning system design and operation.

2. Inadequate information to determine, where to most effectively place monitoring locations.

3. Absence of demonstrated monitoring technologies.

4. Inadequate information and tools supporting integration of indicator data into actionable information.

5. Uncertainty as to what constitutes an "alarm" condition.

6. Absence of guidance or practice as to what action a public water system should take, when alarm conditions are reached.

Roberson and Morley (2005) reported that addressing these needs and demonstrating effective implementation of a contaminant warning system complete with response protocols was necessary prior to significant public water system investment in these types of systems.

The remainder of this report focuses exclusively on the "regulatory-driven" monitoring associated with the TCR, with a particular focus on the objectives articulated previously for the TCR specifically.

2.2 Sampling Plan Design

After monitoring objectives have been established, the next component of a monitoring strategy is the design of a sampling plan.

The sampling plan consists of the number of samples to be collected and frequency of sample collection, along with the sampling locations. According to Kish (1995), "sample design has two

aspects: a selection process, the rules and operations by which some members of the population are included in the sample; and an estimation process (or estimator) for computing the sample statistics, which are sample estimates of population values." The selection process requires applying a clear understanding of the underlying population to establish a spatial and temporal sampling plan; it also involves determining the scale of the decision-making (the smallest subpopulations for which decisions will be made) (EPA, 1994). Applied to the TCR, the selection process consists of the rules and operations that water systems and states use to establish TCR sampling locations, sample event timing, and sampling frequency.

A methodology for establishing a sampling plan utilizing statistically based random selection of sample sites has been presented by Speight, et al., and Speight and DiGiano (2004). Their approach divided the distribution system along spatial lines based on pipe material, pipe diameter, and distance from the treatment plant, but other spatial variables could be used. Analysis of the statistically selected sites was based on a synthetic data set of predicted chlorine residual produced with a free chlorine model of the distribution system (EPANET). Results of the analysis showed that with a random sample site approach, the estimate of error can be calculated. Also, they found no "wrong" sample designs, only designs that were more or less efficient at predicting the proportion of samples with low chlorine residual. Since chlorine acts differently in the distribution system than total coliform, use of a similar approach for TCR sample site selection would require additional investigation.

Crumbling (2002) noted that, historically, environmental sampling programs have focused on quality control of the analytical methods employed in sampling, with relatively little attention devoted to improving the quality of the sampling plan itself by eliminating sampling design biases. She argued that analytical quality is insufficient to ensure sound science, because it ignores the repercussions of multifaceted issues collectively referred to as "representativeness" in sampling programs. Crumbling stated that sampling uncertainty now accounts for the majority of all the data uncertainty and recommended that it be managed by increasing the sampling density and/or by targeting sample collection designs to yield the most valuable information, such as collecting more information at boundaries between "clean" and "dirty" areas and less at obviously "clean" or "dirty" areas.

Simcox (1998) described three sources of bias that are a major cause of inaccurate characterization of water quality in stream sampling networks, which also apply to distribution system sampling networks: design, analytical, and statistical bias. Design bias refers to bias associated with sampling design, which prescribes the location and frequency of sampling. Analytical bias refers to bias associated with the sampling protocols, field equipment, and analytical methodologies. Statistical bias can occur, for example, if an assumption that all samples consist of random, independent, identically distributed measurements from a common underlying population is faulty.

When design bias is present, the sampled and target population do not match. Sources of design bias include spatial design (i.e., location of sampling), temporal design (sampling frequency/times), and scale effects (Simcox, 1998). An example of spatial design bias might be if samples were collected only from water mains near the points of entry that represented the shortest travel times; they would not necessarily be representative of the entire distribution

system (the underlying population). Likewise, temporal bias could be introduced if certain sample sites were sampled in summer and a different set of sample sites sampled during the winter.

Olstadt et al. (2005) demonstrated that there is significant bias introduced through the selection of one approved analytical method vs another; testing 13 different analytical systems Olstadt illustrated almost half of the total coliform tests were susceptible to *Aeromonas spp.*, while the reminder were not. Similarly, some approved test systems failed to provide positive observations for *Citrobacter*, *Enterobacter*, *E. coli*, *Klebsiella*, and *Serratia*, while others responded positively to some or all of these species of coliform bacteria. Olstadt also illustrated that detection of both total coliform and *E. coli* varied as a function of the test water matrix; potential confounders were high levels of heterotrophic bacteria, inadequate media buffering for low pH waters, and incomplete suppression of *Aeromonas spp*. Consequently, with multiple test systems approved for TCR compliance monitoring, observed results are biased based on the selected analytical method.

Eliminating all bias is quite difficult, if not impossible, so the objective of developing a sampling plan is to first understand the effects of bias on subsequent observations and then to control significant sources of bias that would be problematic in achieving the monitoring objectives, given all the relevant constraints, including practicality and costs.

2.3 Understanding the Underlying Population: Coliform Occurrence, Transport, and Persistence in Distribution Systems

Effective monitoring for coliforms requires knowledge of coliform occurrence and behavior in distribution systems. An understanding of coliform occurrence, transport, and persistence in distribution systems is essential to evaluate the effectiveness of various monitoring strategies in meeting the TCR objectives. The occurrence and behavior of coliforms in distribution systems is integrally linked to the monitoring objectives; for example, sampling close to the point-of-entry is reasonable to determine if the treatment process has been compromised. Assumptions about the occurrence distribution of the coliform population are used in the statistical basis for the existing coliform rule, and thus should be reconfirmed in the context of an improved understanding of coliform occurrence and behavior.

2.3.1 Coliform Occurrence in Distribution Systems

There are thought to be three primary sources for microorganisms occurring in distribution systems: 1) microorganisms pass through treatment barriers; 2) microorganisms enter the system from the outside via means other than the treatment process (distribution system intrusion/contamination) or 3) microorganisms multiply within the distribution system, either in the bulk fluid or associated with deposits or biofilms (Besner, Gauthier, Servais, and Camper, 2002). EPA (2002b) summarized literature and reported the following pathogen entry routes:

- Treatment breakthrough
- Leaking pipes, valves, joints, and seals

- Cross-connections and backflow
- Finished water storage vessels
- Improper treatment of materials, equipment, or personnel before entry
- Inadequate distribution system security

Understanding the occurrence patterns for these events and the relative importance of these pathways for coliform entry into distribution systems could help water systems make decisions about the best locations and techniques to sample to achieve the ultimate goal of protecting public health.

2.3.2 Coliform Transport within Distribution Systems

The TCR does not specify what parts of the distribution system should be sampled (e.g., low-flow areas or within storage facilities). Once coliform bacteria exist in the distribution system, they may be further dispersed or aggregated, but relatively little is known about the fate and transport of coliform bacteria within distribution systems and whether their origin influences their subsequent behavior.

Some researchers, using mathematical modeling (Lu, Pratim, and Clark, 1995) and bench experiments (Sethi, 1996), demonstrated how microbial organisms may be transported and attached preferentially to certain areas of a distribution system operating under typical hydrodynamic and physical conditions. Therefore, they concluded that coliform bacteria may be more prevalent in some parts of a system than another (e.g., near pipe expansions or multiple bends and tees, in the vicinity of unused service lines, or in portions of the network where laminar flow conditions prevail). Herson et al. (1991) demonstrated that coliform and indigenous noncoliform organisms are able to accumulate on surfaces, resulting in dramatic differences in microbial numbers between the bulk water phase and surfaces and suggesting a need for alternative techniques for the bacterial monitoring of surfaces other than traditional bulk water phase sampling.

A perception may exist that bacterial contaminants, like soluble chemical contaminants, would disperse uniformly in distribution systems. The dispersion of coliforms bears discussion because of its potential effect on the design of monitoring strategies and its implications for the sample volume and repeat sampling requirements of the existing TCR. McCoy and Olson (1986) reported that the existence of significant numbers of bacterial aggregates in a distribution system sampling study was an important factor that contributed to a substantial underestimation of total cell concentration by colony forming unit assays. Christian and Pipe's (1983) work on coliform occurrence in nine small Pennsylvania community water systems showed that coliform count data could be fitted to either the truncated lognormal or the negative binomial distribution. This finding demonstrated that coliforms were not randomly or uniformly dispersed in these water distribution systems. The researchers also found that the variance of the counts was much greater than the mean.

Other researchers reported similar findings:

> "[Coliform occurrences are] not necessarily uniformly distributed in the network nor in any one location. The coliforms may also be clumped. Springfield, Illinois tried several sampling mechanisms during some of their outbreaks. On one occasion, they collected duplicate samples from the same site; and analyzed them both; one had coliforms too numerous to count and the other had no coliforms. Continuous sampling from a flowing tap revealed serial samples to be sometimes positive and sometimes negative...the probability of actually detecting positive coliforms is probably very, very low because they are not always homogeneously mixed" (Jones, cited in Geldreich, 1988).

In addition to the uncertainties associated with coliform dispersion, there are other questions about coliform transport.

> "Coliforms that slough off biofilms on corroded iron mains during flow reversals might travel as particulates through the system, settling out and resuspending as flow changes occur. Coliforms that break through treatment might be unattached and smaller in grouping size or cluster, and might stay suspended in the water. Do clumps of cells break apart or do single cells clump together? " (Burlingame, 2003).

2.3.3 Coliform Persistence in Distribution Systems

Besner et al. (2002) reviewed literature documenting the ability of coliform bacteria to survive and even grow in pilot distribution studies of drinking water biofilms, identifying water temperature, disinfectant concentration and type, nutrients, sediment buildup, and pipe corrosion as factors influencing the persistence of heterotrophic bacteria and biofilms.

Grayman, et al. (2004) studied and modeled the mixing and aging of water quality within distribution system storage facilities and found areas of long residence times that depress disinfectant residuals and can promote bacterial regrowth, and areas of uneven mixing that can result in zones of older water.

Baribeau et al. (2005) illustrated in bench-scale studies that environmental microorganism strains (*E. coli* was one of the microorganisms tested) were no more resistant than laboratory strains to chlorine. She also found that particulate shielding of microorganisms from disinfection did not consistently interfere with either chlorine or chloramine disinfection.

2.3.4 Alternative Monitoring Parameters for Biofilms

Feliers et al. (2005) demonstrated that biofilm density and species composition in test distribution systems were highly site specific. Feliers et al. noted the single parameter, disinfectant residual, was consistently predictive of biofilm occurrence. While variability was significant in the dataset the there was a consistent trend to lower biofilm levels as disinfectant residuals increased from approximately 0.005 to 1.00 mg/L free chlorine. A decrease of 2-3 log colony forming units was observed with an increase in disinfectant residual from 0.005 to 0.10 mg/L. This observation suggests that the presence of a chlorine residual could be used as an indicator that biofilm levels are under control. Similar findings for total coliform and *E. coli* indicators were not located. Observations by Feliers et al. were consistent with the review paper prepared by Friedman et al. (2005), as well as in surveys of full-scale distribution system episodes and pilot-scale testing by Baribeau et al. (2005). Similarly Spencer et al. (2005) found

heterotrophic plate counts (HPCs) decreasing with change from free chlorine to chloramines. Spencer's work confirms summary information provided by Friedman et al. (2005) that both free chlorine and total chlorine residuals (with respect to chloramines) can provide control of biofilm development. Chlorine residual monitoring is already a component of the SWTR monitoring requirements for public water systems that treat surface water or groundwater under the influence of surface water. Chlorine residual monitoring is generally coordinated with TCR sampling by testing for chlorine residual on each TCR sample. Thus each TCR sample typically provides paired results of total coliform and chlorine residual.

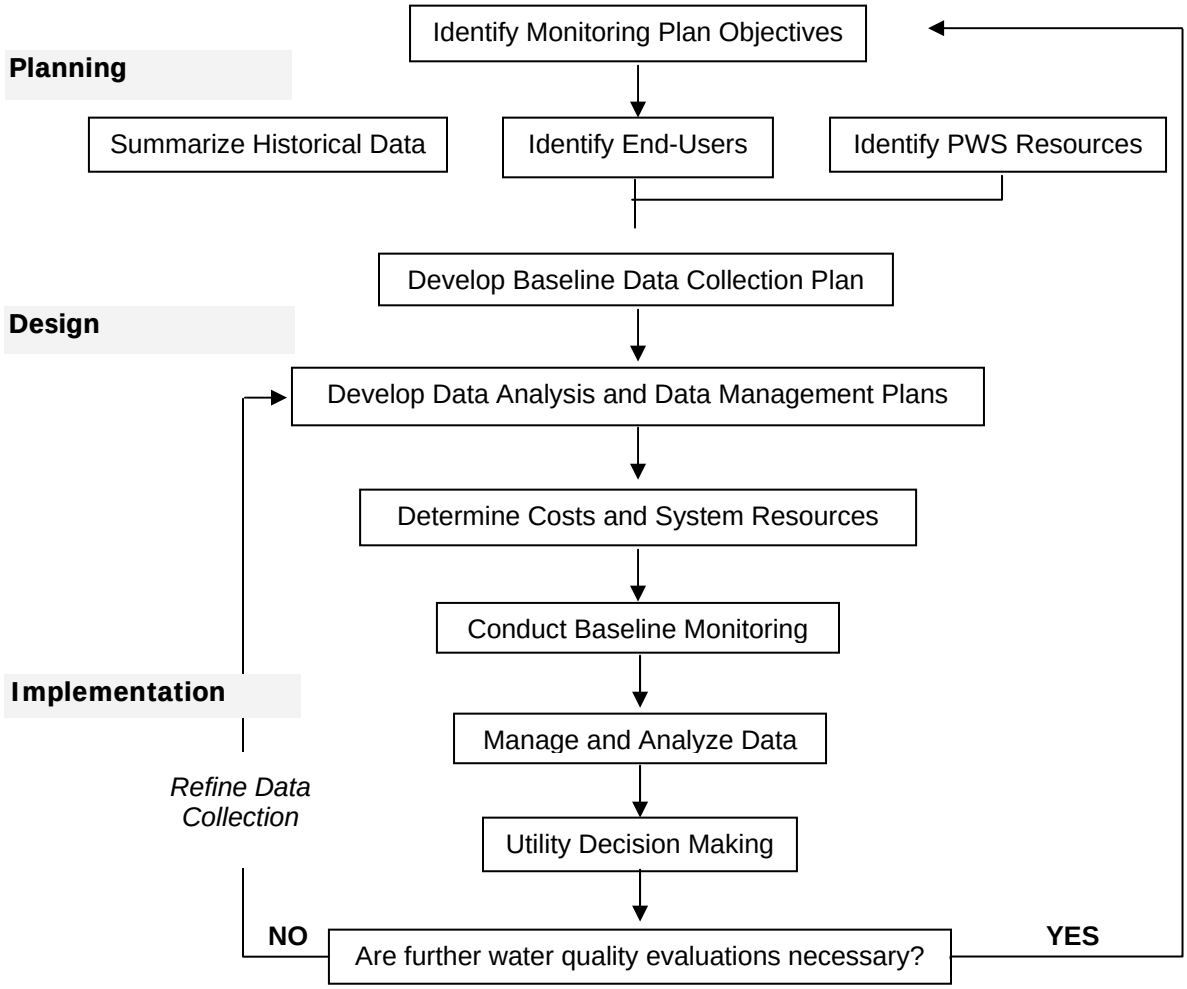
3.0 TCR Objectives and Sampling Design Issues

Total coliform monitoring strategies predate the TCR, with total coliform monitoring beginning at the turn of the century. By 1915 the U.S. Public Health Service standards already included a coliform standard. Consequently, there is a long history of coliform testing practice in drinking water systems (AWWA, 2005). The current monitoring strategies were first developed under the current rule requirements in 1989. Since those initial plans were developed, they have been reviewed in the context of numerous sanitary surveys (sanitary surveys occur at an interval of 3 – 5 years in most states where larger systems are evaluated more frequently). Also, over the intervening 17 years, individual systems and states have had the opportunity to adjust the monitoring strategy to most effectively capture the data targeted in the rule. Figure 2 reflects the overall planning paradigm that has been in place over this period in the absence of specific federal rulemakings. The amount of change that has taken place over this period is state and system specific. The authors could not locate sufficient information to characterize the amount of change that has occurred. Specific states (e.g., California, Ohio, Texas, Utah) have noted that considerable effort has been expended to assure that current monitoring plans are appropriately constructed.

3.1 Linkage of TCR Monitoring Objectives to Other Strategy Components

The TCR refers to three monitoring objectives—a process control objective (treatment performance), a system characterization objective (distribution system integrity), and a contamination detection objective (warning of potential fecal contamination). The ideal sampling design for meeting each objective may be different. For example, monitoring disinfectant residual levels at the TCR monitoring sites may be an example of a disconnected monitoring objective and sampling plan design. Full characterization of the disinfectant residual may be better accomplished through an alternative sampling program as suggested by Speight and DiGiano (2004), rather than at sites selected for TCR monitoring. When the linkage between monitoring objectives and sampling plan design is not explicitly defined, or when multiple objectives exist, the sampling plan design may not achieve the intended monitoring purpose(s).

Figure 2. Water Quality Monitoring Program Development



Source: Adapted from Kirmeyer et al., 2002

3.1.1 Process Control Objective

Concentrating finite resources on monitoring for process control purposes may be worthwhile from the public health perspective. Crumbling (2002) recommended sampling more densely at higher value locations to monitor for process control purposes and suggested concentrating samples frequently at specific sites such as point-of-entry or selected tank effluents. Allen, Clancy, and Rice (2001) argued for increased emphasis on monitoring indicator parameters for process control purposes, compared to direct pathogen monitoring, as a more appropriate means of protecting public health.

3.1.2 System Characterization Objective

Characterizing the system by identifying opportunities for microorganisms to enter the system or to flourish and grow within the system is another objective of the TCR monitoring. The literature generally recognizes that microorganisms can be introduced into the distribution

either through passage through the treatment facility or by introduction to the distribution system through improper maintenance techniques, cross-connections, and distribution system pressure failures. A developing body of research focuses on the potential for pressure transients, which result from abrupt changes in water velocity, to introduce contaminants (LeChevallier, et al. 2002). LeChevallier et al. discussed the potential for environmental water contaminated with fecal indicators to enter a water distribution system during pressure transients via leaks or air relief vents. It is not clear from the available research to what degree this phenomenon affects distribution system integrity (e.g., how likely infectious pathogens are to reach the consumer via this route).

Microorganisms, including coliforms, pathogens and opportunistic pathogens, have demonstrated their ability to survive in biofilms; frequent coliform-positive results may indicate the presence of significant biofilm. Unlined cast iron pipes, particularly older pipes, are especially prone to biofilms (Clement, Camper, and Sandvig, 2002). Some other types of pipe and appurtenance materials are especially prone to biofilm development. A system can address biofilm development in the monitoring plan by placing compliance monitoring samples in portions of the distribution prone to biofilm development based on pipe material, flow regime, or frequent nitrification episodes. However, none of the available information indicates that such measures are being applied to any considerable degree either through state policies or individual utility actions.

3.1.3 Contamination Detection Objective

Contaminants may enter the distribution system at virtually any point through accident or intentional malevolent act. Depending on the contaminant, some degree of protection against microbial contaminants may be provided by maintenance of a disinfectant residual. However, such protection is a function of water quality, disinfectant type and concentration, and contact time. The role of the disinfectant residual is described in detail in a separate white paper.

Detection of contaminants may be best focused at points of particular vulnerability. A recently completed AwwaRF project (Murphy, et al, 2005) assessed vulnerable points of distribution systems from the perspective of terrorism and intentional contamination. Accessible finished water storage facilities are an obvious point of vulnerability. Low-pressure areas may be another point as they are vulnerable to accidental contamination through backflow.

For the more specific goal of detecting fecal contamination, unanswered questions include:

- What is the relative importance of various mechanisms for fecal coliform entry into distribution systems (e.g., intrusion through small holes or breaks in pipes during pressure transients vs. cross connections vs. intrusion via the point of entry)?

- How valuable are repeat monitoring results in investigating and resolving cases of fecal contamination?

Pipes and Christian (1982) wrote:

> "It would be impossible to assure the microbial safety of every drop of water provided by a water system. For a 1 MGD system, there are 37, 800,000 potential 100 mL

samples per day or 1.34 billion samples per month. The fraction of water that is tested for total coliforms is extremely small."

The success of contaminant detection depends on having adequate knowledge of the fate and transport of the contaminant in the distribution system and on the efficacy of the monitoring program.

3.2 Number and Frequency of Samples

The TCR specifies the minimum number of samples and the frequency of sample collection on the basis of population served and other system characteristics such as status as a non-transient-non- community or protected groundwater system. The TCR requires that samples be collected at regular times throughout the month except for certain small groundwater systems that may collect all samples in one day. The TCR currently bases the number of required samples on population. Alternatively, the required sampling could be based on some other measure, such as the water production rate, the size (geographic extent) of distribution system, or the volume of distribution system (diameter and length of pipe, volume of storage), or a statistically-derived number based on desired level of confidence. The population-based approach recognizes that smaller systems may have limited resources available for monitoring.

The objectives of the monitoring strategy are important to establishing an appropriate sampling frequency. If the goal of the sampling is to detect every instance of fecal contamination, then sufficient sampling is key. When a system is not collecting samples frequently enough, or is collecting insufficient numbers of samples overall, then incidents of fecal contamination may not be detected in a timely fashion, even if the sampling locations are geographically and hydraulically representative.

Christian and Pipes (1983) found that the occurrence of coliform bacteria in distribution system samples is adequately represented by either a negative binomial or lognormal distribution. Their work showed that coliforms are not randomly dispersed in a typical water distribution system. Dempsey and Pipes (1986) then used this information to demonstrate how the number of samples collected would affect the frequency of coliform-positive samples. Dempsey and Pipes' mathematical modeling showed that the number of samples used to determine compliance with a frequency-of-occurrence (presence/absence) MCL has a profound effect on the stringency of the rule. They concluded that 60 samples a year would be necessary to make a statistically valid judgment whether less than 10% of a system's water contains coliforms with 95% confidence. This modeling was completed subsequent to the initial regulatory development discussion that small systems would not be overburdened by taking 60 samples a year utilizing presence/absence testing. Small systems were accustomed to taking one sample a month that was then analyzed in five aliquots, resulting in five analyses a month or 60 a year.

In an evaluation of the statistical basis for compliance decision rules in the 1989 TCR, Borup (1992) found:

- Water with acceptable quality may be found to be in violation of the MCL a significant fraction of the time.

- Water with unacceptable quality may be found to meet standards, particularly when fewer than 30 samples are taken. Localized integrity breaches are unlikely to result in TCR violations.

- Large numbers of samples would be required to minimize the two concerns listed above. For example, to ensure with 90% confidence that less than 10% of the water contains coliforms, 90 samples would be required.

- Repeat samples provide little information except in situations where very few original samples are collected.

- TCR decision rules are based on a a set of assumptions that are not often present in water systems, especially during contamination events.

Like Borup, Hamilton (1994) calculated sample sizes (number of samples to be collected) based on the probability of getting false positives or negatives. Speight and DiGiano (2004) calculated an upper bound for sample size when considering chlorine residual decay in distribution systems and were able to generate a range of sample sizes based on different values of confidence level and margin of error, shown in Table 6, where P is the estimate of the overall proportion of samples with below-target chlorine residual concentration.

Table 6. Maximum number of samples from distribution system required to achieve a given margin of error and confidence level, estimated P=0.2

Confidence level (%)	Margin of Error on P				
	0.01	0.02	0.03	0.04	0.05
80	2,146	622	285	162	104
85	2,584	774	357	204	131
90	3,161	991	462	264	171
95	4,031	1,359	645	372	241
97.5	4,767	1,716	830	482	313

Source: Speight and DiGiano, 2004.

Applying Speight and DiGiano's (2004) methodology to TCR sampling would require some consideration of the difference between the persistence of chlorine residual in a distribution system and the theoretical distribution of total coliforms in the distribution system.

Anecdotal information suggests that states have used different approaches in implementing the sampling frequency requirements. Some systems regularly collect samples until they have reached the minimum number of required samples, unless at that number they would exceed the MCL for total coliforms. In that case, the system may continue sampling in an attempt to "dilute" the number of coliform-positive samples to below 5 percent or until time runs out at the end of the month. However, some proponents argue that this practice improves knowledge of water quality in the distribution system by increasing the total number of samples collected beyond the minimum.

3.2.1 Sampling In Consecutive Systems

Some separate water systems are connected so that one of the systems receives water through a wholesale purchase from the supplying water utility. The system purchasing water is considered a consecutive system. Such transfers of water can introduce both spatial and managerial separation between the water treatment plant and the consecutive system's TCR sampling sites. This issue is managed by states on a site-by-site basis under 40 CFR 141.29. This section gives primacy agents the option to consider suppliers and consecutive systems as single systems for the purposes of monitoring under any of the drinking water regulations. Therefore, a primacy agent has the authority to consider a supplier and a consecutive system as a single system, or as separate systems, for purposes of compliance with the monitoring requirements of the SWTR and TCR (EPA, 1999). This authority allows states with EPA concurrence to reduce the overall number of samples taken within individual public water systems based on the overall consecutive system sample plan. This approach is consistent with the underlying random sample strategy for TCR sampling and the population-based sample requirements; it is also consistent with the more recent Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR) compliance-monitoring framework that is also population-based and also allows consolidation of sampling plans across consecutive systems (40 CFR 141.29).

3.3 Sampling Locations

For clarity, the discussion of sampling locations will distinguish between two types: general sampling locations and specific sampling sites (typically, a customer's tap, a hose bib, a hydrant, etc.).

3.3.1 Survey Findings on Sampling Locations

Under the TCR, a public water system must submit sampling plans to the primacy agency for review and approval. This review is in lieu of prescriptive requirements defining the monitoring plan. Narasimhan et al. (2003) in an AwwaRF project report *Sample Collection Procedures and Locations for Bacterial Compliance Monitoring*, surveyed and assessed current state policies regarding TCR sample collection and location selection in California, Washington, Arizona, Michigan, Maine, Alabama, and West Virginia. "Generally, utilities developed sampling plans independently with limited regulatory guidance, and plans are approved and reviewed periodically by primacy agencies." The authors concluded that, in practice, there is no national uniformity in the approaches to select TCR sample locations. Case-by-case determinations are typically made to select specific locations rather than through an overarching state guidance or policy document that would address considerations like the impacts of treatment processes, water quality, pipe materials and booster chlorination facilities. The authors reported that, in general, spatial distribution of sampling locations is based on a visual observation of a system's map.

In addition to variations in sampling location selection, Narasimhan et al. (2003) found variability within the types of sites used for sampling. For example, with regard to sampling of storage facilities, the authors found that sampling practices ranged from collecting samples at each tank to no samples taken in the vicinity of tanks. Similarly, some utilities use a combination of consumer taps and dedicated sampling stations, or strictly one or the other.

The report cited a 1985 survey (which pre-dates the TCR) of 1,796 utilities, undertaken by an AWWA committee on Bacterial Sampling Frequency in Distribution Systems, which also demonstrated wide variations in the types of sites selected by utilities (fire hydrants, storage tanks, pumping stations, commercial buildings, public buildings, and private residences). The same survey responders showed 36 percent of utilities using only fixed locations, 16 percent using only variable locations, and 47 percent using fixed and variable locations. Utilities responding to the survey considered area representation, convenience, centrality, and representation of peripheral areas in their selection of sampling locations.

The TCR requires that systems collect routine total coliform samples at sites that are "representative of water throughout the distribution system" but offers no guidance as to what constitutes "representative." Narasimhan et al. (2004) stated that TCR sample siting plans "have usually been developed based on a visual examination of the distribution system and the convenience of sampling locations." Visual location selection (viewing a system map and selecting sites according to a superimposed grid) may fail to account for parameters that may affect monitoring results, such as variability in typical water demand and flow reversals.

3.3.2 Alternative Sample Location Considerations

Kirmeyer et al. (2002) identified common issues in distribution system monitoring program designs, and suggested potential monitoring stations based on sampling objectives:

- At various points in the system reflecting different water ages
- At locations where water mixes or there is an interface between multiple sources
- At storage facilities
- At locations reflecting different water main materials and conditions
- At locations where supplemental (booster) disinfection is applied (if any), and
- At locations of critical facilities (e.g., hospitals)

Depending on the specific monitoring objectives, researchers target sampling designs to yield information necessary to answer pertinent questions. For example, a system experiencing nitrification may develop a sampling design that includes intensive sampling at locations where disinfectant residual is expected to be low to determine the role of disinfectant decay in nitrification.

The locations of interest in TCR monitoring would depend on the specific objective(s) being considered. For example, locations of critical facilities, such as hospitals and child-care centers, may be of particular interest in contaminant detection strategies, whereas distribution zones known to be susceptible to breaks or leaks may be of particular interest in characterizing distribution system integrity. Many utilities calculate percent leakage on a regular basis. Higher leakage rates may indicate a system is more susceptible to intrusion and that the system practices a lower level of overall maintenance.

3.3.3 Sample Timing

The TCR requires public water systems to collect samples at regular time intervals throughout the month, with one exception. Public water systems that only use ground water under the direct influence of surface water and serve 4,900 persons or fewer, may collect all required samples on a single day if they are taken from different sites. Consequently, sampling in community water systems is not only distributed spatially, but also temporally over the monthly monitoring period.

Guistino (2003) suggested that diurnal variations in distribution pumping schedules and biological and chemical activity may play a role in obtaining a representative grab sample from the distribution system. For example, Guistino noted that the logistics of sampling, sample shipping, and laboratory scheduling tend to encourage a monitoring schedule that occurs early in the day, when water demand is typically high, which may affect observed values. However, for water systems that do most pumping at night and in the early morning, an early sampling schedule may unintentionally bias results toward higher water quality. Sampling that occurs later in the day when all pumping stops would reflect a higher proportion of water from storage in higher [pressure] zones, which is often more susceptible to quality degradation based on longer water age, chlorine residual loss, and increased heterotrophic plate count bacteria. Note that as online chlorine analyzers gain in sue, diurnal and weekly variations within a distribution system can be better understood. In drafting a sampling plan, the utility must balance representative sampling with logistical challenges and resource constraints reflected in a compliance sampling plan, such as:

1. Limitations imposed by the sample method holding times (e.g., time to collect the samples and get the sample to the laboratory for processing),

2. Available certified laboratory capacity,

3. Personnel safety, and

4. Available staff time.

Guistino (2003) proposed procedures for sampling from distribution system reservoirs based on timing of pumping (e.g., for common inlet-outlets, no sooner than one hour after pumping is terminated) and provided guidance on sampling from reservoir hatches, mixers, and dedicated sample lines at reservoirs in order to characterize water quality within individual storage facilities. AWWA's Committee on Bacteriological Sampling Frequency in Distribution Systems (1985) found that sampling is generally arranged by time of day, time of week, and time of month.

3.3.4 Number of Samples per Site

The TCR requires that each compliance sample be collected based on a plan approved by the state; it does not specify that sampling occurs from a discrete location. Similarly the TCR specifies the total number of samples per month; it does not specify the total number of sites a system must use. Consequently, state approved plans reflect state-specific and, in some instances, system-specific approaches. Plans may be framed in one of the following ways:

- A utility may identify exactly the same number of sampling locations as their required number of samples, and collect one sample per month from each site.
- A large pool of sample sites, might be identified with the utility rotating among these sites either randomly or based on a regular routine.
- A utility may identify fewer sites than the number of required samples, collecting samples more frequently than once per month from these sites.

Each of these approaches is based on a different interpretation of the TCR's monitoring requirements. As a result, one system that is collecting 210 samples per month may collect them from 210 discrete sites, and may rotate them such that the next month none of the original sites are revisited. Another system serving the same population size, also collecting 210 samples per month, may have a total of 50 discrete sites that are visited about 4 times per month, every month. Each of these sampling strategies has advantages and disadvantages.

The advantages of the first approach include gathering observations at more (and presumably more geographically diverse) sites within the distribution system over time. However, each individual site is visited very infrequently; consequently, the likelihood of the sampling at a given site coinciding with a coliform occurrence may be extremely low unless an individual site is subject to specific conditions that increase the number of coliforms at that location or has a chronic water contamination problem. The second approach offers a greater ability to evaluate trends in water quality at each site, since data are collected more frequently at each site. Also, systems with a more limited number of sites may be able to better to reduce false positive and false negative samples by achieving better control of the environment at the tap (improved quality control in sampling).

Fixed sampling points provide more uniform information and a more reliable history of water quality, whereas random sampling from different locations is useful when the total number of samples is limited or to provide coverage of all areas when the system is complicated (Narasimhan et al. 2004). Depending on system size, it is often naïve to consider that,by sampling at different sites, the likelihood of detecting an acute, short-term contamination event will be significantly increased.

3.4 Repeat Sampling Monitoring Strategies

Pipes and Christian (1982) and Christian and Pipes (1983) showed that the distribution of coliforms in the distribution system is not uniform. Therefore, repeat samples cannot always be used to determine the validity of a total coliform-positive sample. Collecting more samples (erroneously titled "repeat" samples) allows a utility to get a better measure of the frequency of coliform bacteria in the system. The final TCR prohibits invalidating a total coliform-positive sample because subsequent samples taken at the same tap and/or nearby taps/service connections are total coliform-negative. However, EPA believes that if any repeat sample is total coliform-positive at the same tap as the original total coliform-positive sample, but all repeat samples at nearby service connections are total coliform-negative, this is a strong indication of a domestic or other non-distribution system plumbing problem. Therefore, in this case, the final rule allows the state to invalidate the original total coliform-positive sample. When the state

determines that a coliform-positive result is a domestic or other non-distribution system plumbing problem rather than a distribution system problem, EPA recommends that the state instruct the system to inform all consumers at the affected location of the problem and to advise them to boil their drinking water until the problem is corrected.

As noted in Table 1, the existing TCR requirement is to collect at least one repeat sample from the sampling tap where the original total coliform-positive sample was taken, and at least one repeat sample at a tap within five service connections upstream and at least one repeat sample at a tap within five service connections downstream of the original sampling site within 24 hours. If one or more repeat samples in the set is total coliform-positive, the public water system must collect an additional set of repeat samples within 24 hours. The system must repeat this process until either total coliforms are not detected in one complete set of repeat samples or the system determines that the MCL for total coliforms has been exceeded and notifies the state.

EPA wrote that, conceptually, if coliforms are present in repeat samples at the original tap and also in either (or both) of the upstream and downstream repeat samples, then this occurrence may be taken as evidence that the coliforms may be associated with water under the public water system's control, as opposed to representing only the water within the customer's premises. In contrast, if repeat sampling indicates the absence of total coliforms at upstream and downstream sites, then the source of the contamination may be within the customer's premises (e.g., the building's internal plumbing). Another purpose of repeat sampling is to rule out tap contamination, which happens in non-sterile, general use taps and unsanitary tap environments (Burlingame and O'Donnell, 1993).

The requirement that water systems be able to collect repeat samples within five service connections upstream and downstream of the original sampling site places a constraint on some water systems in selecting their routine sampling locations. Some systems prefer to use commercial or government buildings for all compliance sampling, including upstream and downstream sites, because of the potential need to gain access to the site on very short notice to meet the 24-hour requirement of the rule. Finding sites with three commercial establishments within 10 or 12 service connections along the same main poses an obstacle in many residential neighborhoods.

The TCR requires a public water system to obtain a repeat sample within 24 hours if a positive total coliform sample or a positive *E. coli* or fecal coliform result is obtained. Similar concerns exist about locating sampling locations with accessible alternative sites within five service connections due to the requirement to collect a repeat sample within 24 hours . The state may extend the 24-hour limit on a case-by-case basis if the system has a logistical problem in collecting the repeat samples within 24 hours that is beyond its control. In the case of an extension, the state must specify how much time the system has to collect the repeat samples.

4.0 Appropriateness of TCR Analytical Designs and Statistical Methods

The analytical design, which includes the parameters monitored, the sample collection protocols used, and the analytical methods employed, is the third component of a monitoring

strategy after establishing objectives and designing a sampling plan. The statistical methods used to describe the monitoring data and the statistical methods and assumptions upon which inferences and decisions are based are the final element of the overall monitoring strategy.

4.1 TCR Parameters: Correlation between TCR and Waterborne Disease

The parameters measured under the TCR include total coliforms, fecal coliforms or *E. coli*, and indirectly, under the auspices of the Surface Water Treatment Rule, disinfectant residual or heterotrophic plate count bacteria. In a well-designed monitoring program, the parameters monitored must have relevance for the specific monitoring objective.

Borup (1992) stated that one of the major reasons for the change in TCR monitoring strategy from density to presence-absence in 1989 was that no quantitative relationship between coliform density and pathogen density or between coliform density and the potential for outbreak of waterborne disease had been found to provide a measurable likelihood of the potential for risk as would occur in setting an MCL. Therefore, it was not possible to determine the risk associated with a particular coliform density, and thus a rational MCL could not be established based on coliform densities. However, during at least one investigation of an individual distribution system-related waterborne disease outbreak, investigators found evidence of high levels of total coliforms in the water systems' compliance samples prior to the outbreak (Clark et al. 1996).

Nwachuku, Craun, and Calderon (2002) conducted a retrospective epidemiological study evaluating the utility of TCR compliance as an indicator of outbreak vulnerability and concluded that TCR compliance monitoring is not able to identify those water systems that are generally vulnerable to a waterborne outbreak but is predictive of bacterial outbreaks. In comparing TCR violations for water systems that had and had not reported an outbreak during 1991-1998, they found that few systems experiencing outbreaks (22 percent of the community water systems studied) had violated the TCR MCL in the 12-month period preceding the outbreak. They also found no significant differences in the frequency of "outbreak" and "nonoutbreak" systems' TCR MCL and monitoring violations.

Although their findings generally confirmed that coliforms were frequently found when samples were collected during a time of suspected contamination, Nwachuku et al. (2002) found that routine coliform monitoring was inadequate to predict waterborne outbreaks. The lack of association between total coliform-positive incidents and waterborne disease outbreaks reported by Nwachuku et al. may indicate a problem with the data available to document outbreaks, the indicator parameter itself (which the authors noted, since routine TCR violations were associated with bacterial outbreaks in the study, but not with all types of waterborne disease outbreaks, such as those associated with protozoa), or it may indicate a problem with using TCR monitoring data to support epidemiological analyses, or it may indicate inherent biases in the monitoring strategies employed by water systems.

For example, investigators evaluating the waterborne disease outbreak in Cabool, Missouri, in early 1990 concluded that the TCR compliance monitoring program focused on sites near the center of town, but speculated that routine TCR compliance monitoring may have revealed the

contaminating event if sampling locations had included areas near dead ends or slow flow areas (Geldreich et al, 1992).

Allen, Clancy, and Rice (2000) questioned the value of pathogen monitoring of environmental samples for the purpose of public health protection (e.g., contaminant detection monitoring) and instead urged the use of process control measures to protect public health.

"Today the concept persists among regulatory agencies, public health organizations, and the drinking water community worldwide that public health can only be ensured by pathogen monitoring. …[However], ensuring pathogen-free drinking water may depend on treatment processes and operational practices that result in optimal removal or inactivation of pathogens. Decades of research and field experience have confirmed that well-operated, well-maintained, and well-monitored treatment processes can reliably remove and inactivate pathogens."(Allen, et al. 2000)

These researchers propose that pathogen monitoring be replaced by alternative strategies such as optimizing treatment and maintaining water quality throughout storage and distribution because "past experience and data have shown that pathogen monitoring does not and cannot confirm the absolute presence or absence of infectious microorganisms in drinking water."

A separate white paper addresses the appropriateness of total coliform and *E. coli* as indicators.

4. 2 TCR Sampling Protocols

4.2.1 Sample Collection Logistics

Selecting general, representative locations for sampling is just one step in establishing a sample siting plan. Systems must also select the specific sampling sites in terms of the building and tap. Several researchers have identified common logistical considerations in selecting specific sampling sites for TCR compliance monitoring:

1. Systems must secure permission from site owners or occupants to collect samples.

2. Sites must be safe for water system staff to enter.

3. Taps must be accessible by water system staff; accessible taps located within 5 service connections upstream and downstream must be available in case repeat sampling is required.

4. Systems must manage travel times for efficient sampling, minimizing sample holding times, and conforming to work-day schedules.

5. Sources of potential cross contamination must be minimized.

Kirmeyer et al. (2002) summarized the key advantages and disadvantages of six typical sample collection strategies (see Table 7). This table is not specific to coliform monitoring but it is inclusive of considerations pertinent to coliform monitoring.

Table 7. Comparison of Distribution System Sample Collection Strategies

State	Advantages	Disadvantages
Kitchen Tap	Ease of sample collection.	Contamination potential, accessibility to residential sites may be difficult.
Hose Bib	Accessiblity; ease of sample collection.	Contamination potential; possible access issue.
Fire Hydrant	Accessibility.	Contamination potential; may not represent typical distribution system conditions.
Dedicated Sample Station	Clean, reliable, accessible sampling point. Direct connection to distribution system; ease of sample collection; lockable; tamper-resistant.	Site Security; cost; maintenance; disposal of flushing water.
On-line Analyzer	Continuous, real-time data; potential operational cost savings; improved process control; ease of sample collection.	Analyzers not available for all parameters (i.e., DBPs, bacteria, taste and odor); instrument maintenance required; water disposal; chemical storage and use may be difficult; increased data volume to be reviewed.
Finished Water Storage Facilities	Key location for many monitoring objectives.	Accessibility; may not represent typical distribution system conditions; difficult to collect sample representative of entire contents.

Source: Kirmeyer et al. 2002.

4.2.2 Contamination of Compliance Samples from External Sources

Burlingame and O'Donnell (1993) proposed the concept of "noise" to describe coliform-positive samples in which the organisms originate from external sources other than the distribution system or the water supplied to a customer's service, such as coliform bacteria present in the interior plumbing of a customer's facility. They documented case studies where coliform contamination originated from faucets, building plumbing, and flooded meter pits and recommended measures to control this noise. Burlingame and Choi (1998) recommended practices for improved sampling practices to ensure that representative samples are collected, including sampling apparatus design, installation, and maintenance and flushing practices to discourage coliform growth in sampling lines. Dufresne et al. (1997) and Burlingame and Choi (1998) identified criteria for accepting or rejecting individual sampling stations for TCR compliance based on the potential for environmental contamination.

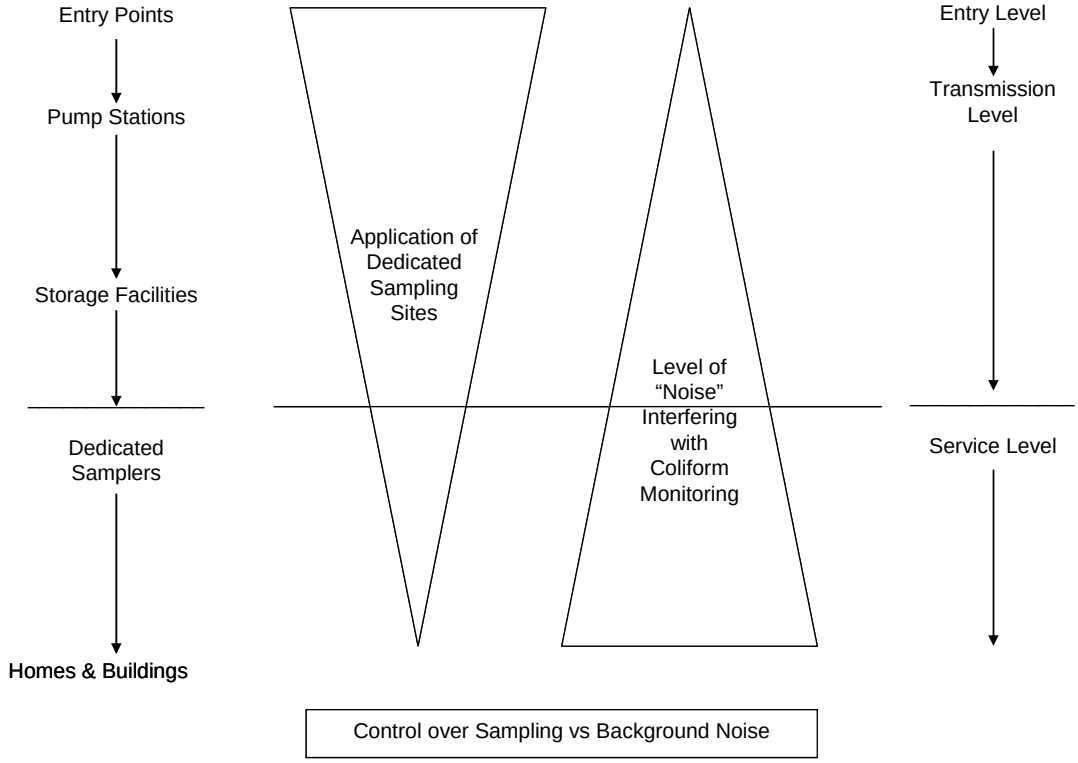
4.2.3 Dedicated Sample Taps

Studies by Ball et al. (1993) and Gueco (1999), among others, showed improvements in TCR compliance after a system converted a large number of its sampling sites to dedicated sampling stations. The City of Philadelphia found that the use of dedicated samplers improved the usefulness of the total coliform indicator by providing higher-quality data that was representative of distribution system water quality and was free of "noise" (Burlingame and O'Donnell, 1993). The water systems attributed the improvements to more carefully controlled sampling environments with fewer opportunities for environmental cross contamination.

Critics have suggested that systems perhaps install dedicated sample taps in portions of the distribution system where they are unlikely to find coliform bacteria.

Burlingame (2004) proposed a conceptual framework for considering the applicability of dedicated sampling sites (Figure 3). Because noise can be controlled more effectively at dedicated sites, and because control points such as the point of entry, pump stations, and storage facilities (the entry and transmission level) have the potential to affect the greatest number of customers, such sites are especially suitable for dedicated sampling sites. Conversely, it is much more difficult to control the sampling environment, and thus the noise, at homes and buildings—the service level. This concept illustrates that it may be much more feasible to reliably achieve the TCR objective of process control compared to the objective of contaminant detection at the service level because of the problem of noise.

Figure 3. Conceptual Framework for the Applicability of Dedicated Sampling Sites



Source: Burlingame, 2004.

4.2.4 Sample Volume

Dempsey and Pipes (1986) demonstrated mathematically the effect of minimum required volume on the probability of compliance, showing that larger sample volumes were more sensitive to detection of coliforms. For example, analyzing varying volumes (25 mL, 50 mL, 100 mL, or 200 mL) of the same theoretical sample containing lognormal-distributed coliforms would yield a determination of approximately 4, 7, 10, or 13 % total coliforms, respectively. Haas (1993) showed the importance of the assumption regarding the underlying distribution of the microorganisms in determining whether it is better to use a large number of small volume

samples or a small number of large volume samples. For data that follow a Poisson distribution, there is no difference. For data that follow a negative binomial distribution, there is a difference, and the answer depends on whether the dispersion parameter, k, varies with sample volume or is independent of sample volume, which he notes can only be determined experimentally.

Research performed by the Honolulu Board of Water Supply to assess the vulnerability of groundwater sources to fecal contamination specifically considered the effect of sample volume on method sensitivity for detecting total coliform, fecal coliform, *E. coli,* and fecal streptococci bacteria (Fujioka et al. 2001). The authors concluded that, "if the standard (100-mL) volume of groundwater samples was tested, 3 of 79 water samples (4%) were positive for total coliform. By increasing the sample volume assayed to 1000 mL, 7 of 79 water samples (9%) were determined to be positive for total coliform…By increasing the volume of sample to be tested from 100 to 1,000 mL, the sensitivity for the detection of total coliform bacteria increased by a factor of two or three." Pryor et al. (2005) illustrated a similar pattern of increased likelihood of positive total coliform sample recovery by increasing sample volume from 100 mL to 2 liters; using an experimental method, detections increased in chlorinated water, though less so than when testing unchlorinated water. In one study, researchers used a composite sampler to improve the detection of coliform bacteria in finished water (Pipes and Minnigh, 1990).

4.2.4 Sample Handling

Pipes and Christian (1982) found that the density of coliforms collected from a distribution system can change within twenty-four hours. However, in a study to determine whether holding time and storage conditions had an effect on *E. coli* densities in surface water, Pope, et al. (2003) reported that most surface water *E. coli* samples analyzed by commonly used methods beyond 8 hours after sample collection can generate *E. coli* data comparable to those generated within 8 hours of sample collection, if samples are held below 10°C and are not allowed to freeze.

4.3 TCR Methods

Coliforms include several genera of bacteria belonging to the family *Enterobacteriaceae*. The historical definition of this group is based on its ability to ferment lactose as used in the test method. The issue of coliform occurrence is complicated by the fact that new methods, with different analytical techniques (media, plating techniques, and incubation methods) produce different results. Thus, the definition of a coliform has changed over time.

EPA has approved a variety of methods for TCR compliance, including methods for total coliforms, fecal coliforms, and *E. coli*. These methods include presence-absence, membrane filter, and multiple tube fermentation techniques. (The presence-absence analytical technique is distinct from the reporting of presence or absence of coliforms in lieu of coliform densities). All three analytical methods use cultivation, on either classical lactose-based media or defined-substrate media, to detect and confirm the presence of total coliforms.

In approving analytical methods for TCR monitoring, U.S. EPA evaluated the effectiveness of these methods (64 Federal Register 67454) and indicated that appreciable false positive rates may be experienced with the routine practice of some TCR methods (see Table 8).

Table 8. False Positive Rates Reported for Commercial Coliform/*E. coli* Tests

Method	Total Coliforms	*E. coli*
E*Colite	16.0%	7.2%
m-ColiBlue24	26.8%	2.5%

The agency noted in that rulemaking that:

> "... the different methods may not be testing for exactly the same set of organisms, and this situation clouds the meaning of the term ``false-positive." Second, the Agency believes that public health would not be jeopardized with the higher false-positive rates because any false-positive result would err on the side of safety. Third, the Agency notes that a single total coliform-positive sample does not result in an MCL violation. Thus the adverse consequence of a ``false-positive" for the system is mitigated." (64 FR 67454).

Burlingame (2004) reported that use of an approved TCR method resulted in false-positive total coliform results caused by the presence of Gram-positive cocci, such as *Staphylococcus* spp. He concluded that a standardized confirmation and identification step is needed before final TCR reporting occurs. The approved methods for coliforms do not adequately address the confirmation of a positive test results.

EPA's December, 1999 notice indicated that the Agency was open to approving analytical methods with equal or even higher false positive rates. This example of how the current list of approved methods introduces substantial uncertainty into the reported level of positive samples illustrates that the effectiveness of the TCR Monitoring Strategy is closely linked to the analytical methods employed. The strengths and limitations of the approved TCR methods are important to understanding the variability in the observed TCR data and the appropriate thresholds for action. There is a separate white paper on the TCR indicators and the associated analytical methods; readers should refer to that paper for more information on the analytical method performance. Also, an AwwaRF research study is currently underway to address the

4.4 Statistical Methods Used In Coliform Rule Development and Compliance Evaluations

4.4.1 Frequency Distribution of Total Coliforms

As discussed in Sections 2.3 and 3.2, research on the frequency of occurrence of coliforms was conducted prior to the promulgation of the 1989 TCR. Borup (1992) noted that the TCR was developed on the basis of the assumption that results from presence-absence testing can be described by the negative binomial distribution. However, he pointed out that one of the underlying assumptions for applying the binomial distribution is that the probability of

obtaining a positive coliform result is the same for each sample (e.g., that the fraction of positive samples is the same at every point in the distribution system over the total time period of sampling). This condition is likely to fail under circumstances that the rule should be designed to identify (e.g., when system integrity is breached, allowing external contamination to enter.) Borup also found problems with the statistical basis of the TCR. He found that water of acceptable quality (95% confidence that less than 10% of the water passing through a distribution system would contain coliforms) may be found to be in violation of the standard a significant portion of the time and that water of unacceptable quality may be found to meet standards, particularly when small numbers of samples are taken.

Hamilton (1994) evaluated the statistical basis for the 1989 TCR and found the regulation potentially allows a higher chance of coliform-contaminated water to be present in a system than intended. He calculated a false pass rate of less than 1% and a false fail rate between 40% and 50% for the TCR when large numbers of samples are taken (>200), and a higher false pass rate for systems collecting small numbers of samples. Hamilton agreed with Borup's findings that use of the binomial distribution may be problematic because it ignores inherent uncertainties (e.g., in sampling mechanisms, storage, transport, analysis) and suggested that the error rates would be even higher if these uncertainties were considered.

4.4.2 Presence/Absence vs Density

The 1989 TCR adopted a presence-absence monitoring strategy that replaced a density approach. According to the EPA, the advantages of the presence-absence strategy include:

- The presence or absence of coliforms is easy to determine, eliminating some of the uncertainty of the estimation-of-density techniques
- Sample transit times are less critical, because a decrease in coliform density seldom results in complete die-out of coliform organisms
- The data truncation errors associated with very high and very low densities measured by the multiple-tube fermentation techniques are eliminated.

USEPA identified the following disadvantages:

- High coliform levels that may occasionally act as important signals of water quality problems are not distinguished by the presence-absence test.
- People accustomed to the density approach may have trouble adjusting to the new approach.

Borup (1992) evaluated the effect of this change in strategy from a statistical perspective and suggested that, for a distribution system whose integrity has been compromised, the MCL would be far less likely to be violated when water quality is impaired in a localized section of the distribution system under the presence-absence strategy than under the density strategy and that systems would therefore have less incentive to investigate and remediate such problems. However, the 1989 TCR added a requirement for repeat sampling to provide incentive to investigate problems.

4.4.3 Limitations of Analytical Methods in Screening for Rare Events

Hrudey and Rizak (2004) proposed a statistical framework for evaluating rare contamination events, demonstrating that, "as the hazard for which the search is being conducted becomes more rare, false positives can be expected to exceed true-positives unless a test offers a false-positive rate approaching the frequency of the hazard." They illustrated the situation using a hypothetical analytical method with only a 3 percent false positive rate, showing that it would need to have a hazard frequency of at least one in 33, or 3 percent, to have a 50-50 chance of any positive being correct. Since total coliforms apparently occur in compliant public water systems at rates sometimes far below 5 percent, this concept may be a useful tool for evaluating the acceptability of total coliform analytical methods.

The following two tables (Tables 9 and 10) illustrate the occurrence of total coliforms based on regulatory monitoring compilations from 14 states and 6 example public water systems.

Table 9. Total Coliform Occurrence in Example States

State	Number of Years of Data Collected	Number of Total Coliform Samples Collected	Percent of Positive Total Coliform Samples
MO	6	467,896	0.05%
IL	6	680,738	0.40%
PA	6	878,849	0.53%
OH	6	692,051	0.66%
FL	2	537,495	0.74%
AZ	5	328,298	1.76%
IA	6	303,110	1.96%
NH	6	74,993	2.18%
WA	6	671,118	2.69%
NE	6	157,165	3.42%
IN	6	437,006	3.64%
NC	6	436,338	4.07%
VA	6	227,474	4.41%
MD	6	311,925	4.70%

Source: Rosen et al. 2006.

5.0 Alternative Distribution System Monitoring Strategies

In evaluating monitoring strategies under the TCR, it may be useful to consider alternative distribution system monitoring strategies described in the literature and in recent international forums. These concepts include fully developed sampling plan strategies as well as ideas that may be applicable in a restructured TCR as triggers for action, for example, or as follow-up actions. The following concepts are discussed in this section:

Table 10. Total Coliform Occurrence at Example Utilities

PWS	Number of Years of Data Collected	Number of Total Coliform Samples Collected	Percent of Positive Total Coliform Samples	Maximum Monthly Percent Positive Total Coliform Samples	Number of Positive E. coli Samples
Virginia PWS serving > 100,000	9	24,351	0.12%	1.25%	1
Pennsylvania PWS serving > 100,000	5	28,599	0.15%	nc*	2
Florida PWS (1) serving >100,000	6	28,624	0.22%	nc*	11
Florida PWS (2) serving >100,000	2	17,003	0.27%	nc*	6
Florida PWS (3) serving >100,000	8	22,444	0.78%	6.18%	3
Private Utility (multi-State)	8	12,882	2.39%	2.18%	6

Note: * NC equals "not calculated"
Source: Rosen et al. 2006.

- AwwaRF Guidance Manual: *Developing a Bacterial Sampling Plan*
- Statistically-Based Sampling Network Design
- Use of Hydraulic Models to Aid in Monitoring Station Selection
- Hazard Analysis Control Evaluation Process
- Sampling for Rare Events (Inverse Sampling)
- Sampling at Worst Case Areas
- Statistical Process Control Theory
- Tiered Response Action Approach
- Use of Alternative Process Control and System Characterization Tools

An AwwaRF project, "Methodologies for assessing and improving water quality sampling programs in drinking water distribution system," which has not yet reported its findings, may shed light on additional strategies.

5.1 AwwaRF Guidance Manual: *Developing a Bacterial Sampling Plan*

The AwwaRF Guidance Manual *Developing a Bacterial Sampling Plan* provided rational guidelines for utilities of all sizes to design effective bacterial sampling plans (Narasimhan and Brereton, 2004). The manual lays out a six-step approach to develop a distribution system bacterial sampling plan. The approach begins by allocating the required number of TCR compliance samples among sectors, the number of which are dictated by population served, ranging from one sector for small systems to six sectors for systems serving upwards of 3.9 million persons. The recommended number of sectors is based on logistical considerations (10-20 samples that can be collected per day by one sampler within a sector). Spatial sectors are defined using political boundaries, pressure zones, influence zones of water sources, pressure zones, and so forth. Next, the total number of required samples is divided among each sector on the basis of population. The approach presumes collection of the number of samples specified in the TCR unless the system cannot be adequately characterized by that number of samples. Critical factors that influence bacterial monitoring results are considered next, and the number of samples may be adjusted above the minimum requirements of the TCR to adequately characterize water quality. Critical factors include source variation, disinfectant level, pressure zones, pipe material or age, demand variation, land use variation, dead ends, sensitive populations, reservoirs or storage tanks, and other considerations such as nitrification history. Once sites are selected, then the specific taps are selected; the taps are chosen considering accessibility, hydraulic conditions, and other factors that could influence bacterial results by representing building or site contamination as opposed to system water quality in the local area.

5.2 Statistically-Based Network Design

Bahadur et al. (2003) stated that the best sampling design "will be based on an objective approach, dependent on a number of factors, including the desired statistical power and level of confidence in the final decision and the variability of the environmental attribute of interest." Although Pipes (1988) suggested that stratified, random sampling could be applied to water distribution systems, application of statistical approaches to network sampling designs has been limited until recently.

Speight , Kalsbeek, and DiGiano(2004) proposed a methodology for randomization and stratification to allow a distribution system sampling plan to identify optimal locations and sample collection frequencies to meet specific data goals. For example, for a sample siting plan to be representative spatially, the utility's service area could be divided into strata representing various categories of radial distance to the treatment plant. For representative sample collection timing, "peak" and "non-peak" strata could be defined. The total number of samples required for a specific confidence level and margin of error would be allocated among the various strata. The advantages of this approach in providing statistically valid samples at a defined level of confidence would need to be balanced with practical considerations regarding sample size (Speight et al, 2004).

5.3 Use of Hydraulic Models to Aid in Monitoring Site Selection

Various researchers have considered the use of hydraulic modeling to aid in selecting monitoring sites within distribution systems or to test the effectiveness of a particular monitoring plan if a metric for the plan's effectiveness can be established. In addition, several recent research projects have sought to determine optimal monitoring strategies through the use of hydraulic modeling or network analysis. The impetus for this work has been the concern about purposeful contamination of distribution systems and where monitors should be located to best observe the contamination. A major issue is whether the monitoring objectives associated with monitoring for security purposes are similar to the monitoring objectives associated with the TCR. Most of the security-related modeling approaches assume a single point of contaminant introduction, which may or may not be applicable for TCR monitoring.

Lee, Deininger, and Clark (1991) attempted to systemize and optimize monitoring station selection using a mathematical model in conjunction with a hydraulic model and assuming that downstream water quality could be used to infer upstream water quality. By considering the routes that water could theoretically travel (the pathways) from the point-of-entry to each node of the model, along with each node's contribution to downstream water demand, they could determine the theoretical "coverage" that a given arrangement of sampling stations would provide in characterizing water quality systemwide. This technique may be able to represent more of the distribution system with fewer samples. One limitation is that the technique may be biased toward monitoring for coliform bacteria that enter the distribution system via the treatment plant or source water (Narasimhan et al. 2003) rather than other routes within the system.

Berry, Fleischer, Hart, and Phillips (2003) used hydraulic modeling with an integer programming approach to optimize sensor placement in municipal water networks to minimize the fraction of the population at risk. They noted other objectives could be minimizing the volume of water consumed before detection or minimizing the time before detection, for example. Ostfeld and Salomons (2003) used a genetic algorithm approach with EPANET to optimize the layout of a detection system for introduced contaminants, considering the unsteady hydraulics, dilution effects, and decay properties of the water quality constituents. Their methodology locates a set of monitoring stations intended to capture the maximum volume of contaminant exposure to the public at a concentration higher than a minimum hazard level. Bhadur, Samules, Grayman, Amstutz, and Pickus (2003) used a combination of hydraulic modeling with extended period simulation using PipelineNet and GIS to select nodes for monitoring in case of contaminant intrusion. The PipelineNet system converts hydraulic and water quality parameter modeling output files into ArcView shapefiles, which are displayed in ArcView along with GIS layers depicting the distribution system and other infrastructure.

Despite the potential usefulness of hydraulic modeling tools, developing, calibrating, and maintaining a valid distribution system hydraulic model is a very costly endeavor—one that remains beyond the reach of many water systems.

5.4. Approaching the Distribution System as a Process

One of the primary objectives of the TCR is to serve as a process control reliability check in the multiple-barrier approach. Coliform sampling provides a quality control check on the overall treatment, transmission, and distribution process when it focuses on sampling locations that are reflective of overall or average conditions or that are identified as critical process control points.

As noted previously, a separate white paper is addressing the identification of critical control points for water distribution systems. Critical control point monitoring using multiple parameters has its origins in Hazard Analysis and Critical Control Point (HACCP). Currently, Australia employs HACCP as the overall framework for assuring drinking water quality from catchment to tap. The HACCP model is also being considered in Canada as the provinces continue to respond to the Walkerton outbreak.

In the international arena, the World Health Organization (WHO) adapted the HACCP concept to drinking water. WHO is currently advising both industrialized and developing countries to consider the use of "Water Safety Plans" as a management framework for public drinking water systems. In May, 2004 EPA recommended that the HACCP approach be considered in the revision of the TCR.

5.5 Sampling for Rare Events (Inverse Sampling)

Coliform occurrences in TCR compliance sampling programs are generally rare events—occurring in fewer than 5 percent of samples collected by compliant water systems. Occurrences of *E. coli* or fecal coliforms are even less frequent. Water utilities may be able to draw upon the experience of other disciplines for monitoring strategies aimed at sampling for rare events. For example, it may be possible to adapt some of the methodologies used in the public health area for syndromic surveillance. Statistical methods such as aberration detection algorithms are frequently used by epidemiologists to assist them in identifying and characterizing disease outbreaks by rapidly assessing changes in frequencies and rates of different health outcomes and for the characterization of unusual trends or clusters (Hutwagner, Thompson, Seeman, and Treadwell, 2003). Applying such surveillance methodologies to coliform occurrence data might also promote a better understanding of the link between waterborne outbreaks and coliform occurrence. To use such tools would likely involve confirming the underlying distribution of coliform data in water systems; developing or adapting an applicable methodology; addressing the question of whether coliform events are indeed random, independent variables (if required by the algorithm); and considering the role of distribution system hydraulics.

5.6 Sampling at the Worst Case Areas

It is possible to conceive of a monitoring strategy that would attempt to maximize the number of positive samples by sampling intensively in areas that are most likely to harbor them. This approach is premised on the assumption that finding and preventing contamination at these locations is an efficient and effective means of ensuring that contamination does not occur throughout the entire distribution system. For example, this monitoring strategy might focus

on sampling in areas of low flow, at dead ends, at stagnant areas within storage facilities, in corroded cast iron pipes, and in areas where low disinfectant residuals occur frequently. Such a strategy would presume that we can identify areas that are susceptible to coliforms and might involve restructuring the compliance system to reward systems for seeking out and finding coliforms and remedying any problem areas.

5.7 Statistical Process Control Theory

It may be possible to apply statistical process control concepts, such as control charts, to develop a sampling plan design to capture either data excursions of significance or gradual water quality deterioration, such as a gradual increase in background levels of total coliforms or other parameters of significance. This approach may be particularly applicable for the process control objective of monitoring at the points of entry or at storage facilities. It may also be applicable for characterizing areas that are particularly susceptible to biofilm growth. The number of samples needed for this sampling framework is most likely beyond the capabilities of manual grab sampling and analysis. However, rapid advances in on-line monitoring and automation in the drinking water arena are occurring, and the growing opportunities for real-time decision-making tools to aid in public health protection should be considered.

5.8 Tiered Response Action Approach

Total-coliform–positive results could trigger tiered investigations and response actions. It is reported (DWI, 2000, cited in Health Canada, 2004) that "the Drinking Water Inspectorate of England and Wales has included in its regulations a mandatory value of zero coliforms per 100 mL in water leaving treatment works, a mandatory value of zero coliforms per 100 mL in 95% of samples for water in service reservoirs, and a non-mandatory value of zero coliforms per 100 mL at the consumer's tap. In these regulations, non-mandatory values do not need to be met, but exceedances need to be investigated and actions taken only if they represent a health risk."

A few examples of such investigations and actions include the following:

- Determine coliform density. Some researchers (Borup, 1992) predicted that the change from considering coliform densities to a presence/absence-based MCL would result in the loss of valuable information on localized problems in portions of the distribution system. Therefore, it may be useful to require systems to analyze coliform density under some circumstances.

- Sample more intensively near the areas where coliforms are found.

- Undertake a unidirectional flushing program to remove accumulated sediments and biomass.

- Use mapping tools to graphically display locations of coliform occurrences and potential influences, such as distribution system maintenance activities, areas of low pressure or low water demand, etc.

- Employ microbial source tracking to determine whether fecal contamination originates with human or animal sources. According to the National Research Council (2004), there are several promising microbial source tracking techniques in development.

- Undertake a comprehensive cross connection control program.

Many more possible activities could be envisioned for better investigating and resolving coliform occurrences.

5.9 Use of Alternative Process Control and System Characterization Tools

Total coliform is monitored, in part, as a process control and system characterization tool—to evaluate the effectiveness of the treatment process in inactivating bacteria and to determine whether bacteria are finding post-treatment routes into the distribution system. Reasoner (1990) proposed using heterotrophic plate counts (HPC) for several similar objectives, including monitoring the efficiency of the water treatment process, assessing the integrity of the distribution system (e.g., assessing changes in finished-water quality during distribution and storage), and confirming that high HPC levels were not interfering with coliform/*E. coli* measurements. Given that coliform occurrences are relatively rare, whereas HPC occurrences are more widespread, there may be advantages in monitoring HPC rather than total coliforms for process control and system characterization, from a statistical perspective. However, monitoring for HPC would not provide the warning of potential fecal contamination that monitoring for total coliforms provides.

6.0 Summary of Findings and Research Needs

6.1 Ongoing Research

The following seven ongoing research projects were identified through a review of AwwaRF and DRINK databases. Ongoing research projects that relate directly to TCR monitoring strategies are included. Projects more closely related to other TCR white papers were not included in this listing:

- Assessing and Improving Water Quality Sampling Programs in Drinking Water Distribution Systems AwwaRF #3017, Malcolm Pirnie, Inc. This project is to identify distribution-system-sampling needs and develop methods and tools to help utilities evaluate sampling plans and improve them to achieve multiple goals. Results are due August 2007.

- Testing and Evaluation of Currently-Used Water Monitoring Technologies for their Ability to Meaningfully Respond to Changes in Drinking Water Quality. EPA-National Homeland Security Research Center. This project involves controlled tests to evaluate currently used water monitoring technologies and their ability to respond to changes in drinking water quality due to the introduction of various contaminants. The research conducted will support large and small treatment water

utilities with particular emphasis on distribution systems. All test and evaluation research will be conducted under controlled conditions using technologies currently located at the Water Awareness Technology Evaluation Research and Security (WATERS) Center located at EPA's Test & Evaluation (T&E) Facility in Cincinnati, OH. Preliminary results were reported in 2005 but further testing is planned (EPA, 2005).

- Identification of Heterotrophic Bacteria That Colonize Chloraminated Drinking Water Distribution Systems, AwwaRF #3088, Univerisity of Wisconsin at Madison. This project's goal is identifying and quantifying the heterotrophic bacteria that colonize chloraminated drinking water distribution systems. It anticipates determining whether bench- and pilot-scale chloraminated systems are adequate models to study the type of bacteria that colonize full-scale systems. It will also formulate mechanisms and hypotheses for the role of these bacteria as the critical microbial group in nitrification of chloraminated distribution systems. Results are due April 2008.

- Strategy to Manage and Respond to Total Coliforms and *E. coli* in the Distribution System, AwwaRF #3116, HDR/EES. The purpose of the project is to develop a practical guide to help utilities manage microbial water quality and develop response strategies to total coliforms and *E. coli* events in the distribution system. Will also include the application of available microbial source tracking tool(s) for the determination of contamination source(s) in the distribution system. The results of this project bear on determining under which conditions upstream and downstream sampling are important to the monitoring strategy. Results are due January, 2009.

- Development of Performance Criteria and Measurement Parameters for On-Line Monitoring Instrumentation, AwwaRF #2978, Sandia National Laboratories. This project will develop performance criteria for existing on-line monitoring instrumentation. It will determine surrogates for evaluating and testing the performance of a select group of on-line instruments for possible detection of chemical or biological contaminants in the distribution system. While this project is focused on security related distribution system monitoring, the information collected will be relevant to the TCR monitoring strategy discussion. Results are due April 2008.

- Data Processing and Analysis for Online Distribution System Monitoring, AwwaRF #3035, Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia. The aim of this project is to examine data processing methods that can distinguish normal variability from patterns related to specific contamination events. Will develop a general data processing approach to assist water quality managers and water system operators to detect abnormal patterns in online monitoring data. This project bears on the integration of chlorine residual or other parameters for which there are on-line monitoring devices for the TCR monitoring framework. Results are due August, 2007.

- Cross-Connection and Backflow Vulnerability: Monitoring and Detection, AwwaRF #3022, American Water. This project is intended to determine the most effective technologies available, as well as recommended placement, to prevent, monitor and rapidly detect contamination in the distribution system related to cross-connection and backflow events. Results are due January 2009.

6.2 Research Gaps

The fundamental problem in designing a total coliform monitoring program is the lack of understanding of the processes that must be monitored. As a result, some of the research needs pertain to understanding coliform behavior and causal factors. Other research needs pertain more directly to addressing different objectives in monitoring under different system-specific conditions. At present, research gaps include:

1. A clear and specific definition of the objectives of the TCR and/or other monitoring program, including metrics for each objective. A comprehensive evaluation of how to develop an optimal water quality sampling and monitoring network that is not single purpose, but meets the public water system's need for monitoring to assure operational control, regulatory compliance, customer acceptance, and other purposes.

2. A good understanding of the behavior, fate and transport of microbial contaminants entering the distribution system by different pathways, including a systematic assessment of the role of biofilms in total coliform and *E. coli* occurrence in distributed water; a systematic assessment of the frequency of events that are likely to introduce microbial contaminants into the distribution system; and the factors most significant in determining the frequency and amount of microbial contamination introduced to distributed water.

3. An understanding of the effect of system-specific variables such as disinfectant type or system configuration on microbial contaminant behavior.

4. A systematic evaluation of response strategies following an observation of elevated total coliform or *E. coli* levels in the distribution system.

5. An understanding of the extent to which chlorine-resistance is developing in target species and impacts of such resistance (if it exists) on analytical method performance.

6. An understanding of the connection between flow, chlorine residual, and coliform bacteria occurrence in a distribution system and integrating this understanding into monitoring development approaches utilizing modeling tools.

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Appendix A.
A Partial Excerpt of Section 141 of the Code of Federal Regulations Pertinent to the Total Coliform Rule Monitoring Requirements

in this section apply to filtered systems until June 29, 1993. The requirements in this section apply to unfiltered systems that the State has determined, in writing pursuant to §1412(b)(7)(C)(iii), must install filtration, until June 29, 1993, or until filtration is installed, whichever is later.

(a) One turbidity unit (TU), as determined by a monthly average pursuant to §141.22, except that five or fewer turbidity units may be allowed if the supplier of water can demonstrate to the State that the higher turbidity does not do any of the following:

(1) Interfere with disinfection;

(2) Prevent maintenance of an effective disinfectant agent throughout the distribution system; or

(3) Interfere with microbiological determinations.

(b) Five turbidity units based on an average for two consecutive days pursuant to §141.22.

[40 FR 59570, Dec. 24, 1975]

§141.15 Maximum contaminant levels for radium-226, radium-228, and gross alpha particle radioactivity in community water systems.

The following are the maximum contaminant levels for radium-226, radium-228, and gross alpha particle radioactivity:

(a) Combined radium-226 and radium-228—5 pCi/1.

(b) Gross alpha particle activity (including radium-226 but excluding radon and uranium)—15 pCi/1.

[41 FR 28404, July 9, 1976]

EFFECTIVE DATE NOTE: At 65 FR 76745, Dec. 7, 2000, §141.15 was removed, effective Dec. 8, 2003.

§141.16 Maximum contaminant levels for beta particle and photon radioactivity from man-made radionuclides in community water systems.

(a) The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water shall not produce an annual dose equivalent to the total body or any internal organ greater than 4 millirem/year.

(b) Except for the radionuclides listed in Table A, the concentration of man-made radionuclides causing 4 mrem total body or organ dose equivalents shall be calculated on the basis of a 2 liter per day drinking water intake using the 168 hour data listed in ''*Maximum Permissible Body Burdens and Maximum Permissible Concentration of Radionuclides in Air or Water for Occupational Exposure,*'' NBS Handbook 69 as amended August 1963, U.S. Department of Commerce. If two or more radionuclides are present, the sum of their annual dose equivalent to the total body or to any organ shall not exceed 4 millirem/year.

TABLE A—AVERAGE ANNUAL CONCENTRATIONS ASSUMED TO PRODUCE A TOTAL BODY OR ORGAN DOSE OF 4 MREM/YR

Radionuclide	Critical organ	pCi per liter
Tritium	Total body	20,000
Strontium–90	Bone marrow	8

[41 FR 28404, July 9, 1976]

EFFECTIVE DATE NOTE: At 65 FR 76745, Dec. 7, 2000, §141.16 was removed, effective Dec. 8, 2003.

Subpart C—Monitoring and Analytical Requirements

§141.21 Coliform sampling.

(a) *Routine monitoring.* (1) Public water systems must collect total coliform samples at sites which are representative of water throughout the distribution system according to a written sample siting plan. These plans are subject to State review and revision.

(2) The monitoring frequency for total coliforms for community water systems is based on the population served by the system, as follows:

TOTAL COLIFORM MONITORING FREQUENCY FOR COMMUNITY WATER SYSTEMS

Population served	Minimum number of samples per month
25 to 1,000[1]	1
1,001 to 2,500	2
2,501 to 3,300	3
3,301 to 4,100	4
4,101 to 4,900	5
4,901 to 5,800	6
5,801 to 6,700	7
6,701 to 7,600	8

TOTAL COLIFORM MONITORING FREQUENCY FOR COMMUNITY WATER SYSTEMS—Continued

Population served	Minimum number of samples per month
7,601 to 8,500	9
8,501 to 12,900	10
12,901 to 17,200	15
17,201 to 21,500	20
21,501 to 25,000	25
25,001 to 33,000	30
33,001 to 41,000	40
41,001 to 50,000	50
50,001 to 59,000	60
59,001 to 70,000	70
70,001 to 83,000	80
83,001 to 96,000	90
96,001 to 130,000	100
130,001 to 220,000	120
220,001 to 320,000	150
320,001 to 450,000	180
450,001 to 600,000	210
600,001 to 780,000	240
780,001 to 970,000	270
970,001 to 1,230,000	300
1,230,001 to 1,520,000	330
1,520,001 to 1,850,000	360
1,850,001 to 2,270,000	390
2,270,001 to 3,020,000	420
3,020,001 to 3,960,000	450
3,960,001 or more	480

[1] Includes public water systems which have at least 15 service connections, but serve fewer than 25 persons.

If a community water system serving 25 to 1,000 persons has no history of total coliform contamination in its current configuration and a sanitary survey conducted in the past five years shows that the system is supplied solely by a protected groundwater source and is free of sanitary defects, the State may reduce the monitoring frequency specified above, except that in no case may the State reduce the monitoring frequency to less than one sample per quarter. The State must approve the reduced monitoring frequency in writing.

(3) The monitoring frequency for total coliforms for non-community water systems is as follows:

(i) A non-community water system using only ground water (except ground water under the direct influence of surface water, as defined in §141.2) and serving 1,000 persons or fewer must monitor each calendar quarter that the system provides water to the public, except that the State may reduce this monitoring frequency, in writing, if a sanitary survey shows that the system is free of sanitary defects. Beginning June 29, 1994, the State cannot reduce the monitoring frequency for a non-community water system using only ground water (except ground water under the direct influence of surface water, as defined in §141.2) and serving 1,000 persons or fewer to less than once/year.

(ii) A non-community water system using only ground water (except ground water under the direct influence of surface water, as defined in §141.2) and serving more than 1,000 persons during any month must monitor at the same frequency as a like-sized community water system, as specified in paragraph (a)(2) of this section, except the State may reduce this monitoring frequency, in writing, for any month the system serves 1,000 persons or fewer. The State cannot reduce the monitoring frequency to less than once/year. For systems using ground water under the direct influence of surface water, paragraph (a)(3)(iv) of this section applies.

(iii) A non-community water system using surface water, in total or in part, must monitor at the same frequency as a like-sized community water system, as specified in paragraph (a)(2) of this section, regardless of the number of persons it serves.

(iv) A non-community water system using ground water under the direct influence of surface water, as defined in §141.2, must monitor at the same frequency as a like-sized community water system, as specified in paragraph (a)(2) of this section. The system must begin monitoring at this frequency beginning six months after the State determines that the ground water is under the direct influence of surface water.

(4) The public water system must collect samples at regular time intervals throughout the month, except that a system which uses only ground water (except ground water under the direct influence of surface water, as defined in §141.2), and serves 4,900 persons or fewer, may collect all required samples on a single day if they are taken from different sites.

(5) A public water system that uses surface water or ground water under the direct influence of surface water, as defined in §141.2, and does not practice filtration in compliance with Subpart

H must collect at least one sample near the first service connection each day the turbidity level of the source water, measured as specified in §141.74(b)(2), exceeds 1 NTU. This sample must be analyzed for the presence of total coliforms. When one or more turbidity measurements in any day exceed 1 NTU, the system must collect this coliform sample within 24 hours of the first exceedance, unless the State determines that the system, for logistical reasons outside the system's control, cannot have the sample analyzed within 30 hours of collection. Sample results from this coliform monitoring must be included in determining compliance with the MCL for total coliforms in §141.63.

(6) Special purpose samples, such as those taken to determine whether disinfection practices are sufficient following pipe placement, replacement, or repair, shall not be used to determine compliance with the MCL for total coliforms in §141.63. Repeat samples taken pursuant to paragraph (b) of this section are not considered special purpose samples, and must be used to determine compliance with the MCL for total coliforms in §141.63.

(b) *Repeat monitoring.* (1) If a routine sample is total coliform-positive, the public water system must collect a set of repeat samples within 24 hours of being notified of the positive result. A system which collects more than one routine sample/month must collect no fewer than three repeat samples for each total coliform-positive sample found. A system which collects one routine sample/month or fewer must collect no fewer than four repeat samples for each total coliform-positive sample found. The State may extend the 24-hour limit on a case-by-case basis if the system has a logistical problem in collecting the repeat samples within 24 hours that is beyond its control. In the case of an extension, the State must specify how much time the system has to collect the repeat samples.

(2) The system must collect at least one repeat sample from the sampling tap where the original total coliform-positive sample was taken, and at least one repeat sample at a tap within five service connections upstream and at least one repeat sample at a tap within five service connections downstream of the original sampling site. If a total coliform-positive sample is at the end of the distribution system, or one away from the end of the distribution system, the State may waive the requirement to collect at least one repeat sample upstream or downstream of the original sampling site.

(3) The system must collect all repeat samples on the same day, except that the State may allow a system with a single service connection to collect the required set of repeat samples over a four-day period or to collect a larger volume repeat sample(s) in one or more sample containers of any size, as long as the total volume collected is at least 400 ml (300 ml for systems which collect more than one routine sample/month).

(4) If one or more repeat samples in the set is total coliform-positive, the public water system must collect an additional set of repeat samples in the manner specified in paragraphs (b) (1)–(3) of this section. The additional samples must be collected within 24 hours of being notified of the positive result, unless the State extends the limit as provided in paragraph (b)(1) of this section. The system must repeat this process until either total coliforms are not detected in one complete set of repeat samples or the system determines that the MCL for total coliforms in §141.63 has been exceeded and notifies the State.

(5) If a system collecting fewer than five routine samples/month has one or more total coliform-positive samples and the State does not invalidate the sample(s) under paragraph (c) of this section, it must collect at least five routine samples during the next month the system provides water to the public, except that the State may waive this requirement if the conditions of paragraph (b)(5) (i) or (ii) of this section are met. The State cannot waive the requirement for a system to collect repeat samples in paragraphs (b) (1)–(4) of this section.

(i) The State may waive the requirement to collect five routine samples the next month the system provides water to the public if the State, or an agent approved by the State, performs

a site visit before the end of the next month the system provides water to the public. Although a sanitary survey need not be performed, the site visit must be sufficiently detailed to allow the State to determine whether additional monitoring and/or any corrective action is needed. The State cannot approve an employee of the system to perform this site visit, even if the employee is an agent approved by the State to perform sanitary surveys.

(ii) The State may waive the requirement to collect five routine samples the next month the system provides water to the public if the State has determined why the sample was total coliform-positive and establishes that the system has corrected the problem or will correct the problem before the end of the next month the system serves water to the public. In this case, the State must document this decision to waive the following month's additional monitoring requirement in writing, have it approved and signed by the supervisor of the State official who recommends such a decision, and make this document available to the EPA and public. The written documentation must describe the specific cause of the total coliform-positive sample and what action the system has taken and/or will take to correct this problem. The State cannot waive the requirement to collect five routine samples the next month the system provides water to the public solely on the grounds that all repeat samples are total coliform-negative. Under this paragraph, a system must still take at least one routine sample before the end of the next month it serves water to the public and use it to determine compliance with the MCL for total coliforms in §141.63, unless the State has determined that the system has corrected the contamination problem before the system took the set of repeat samples required in paragraphs (b) (1)–(4) of this section, and all repeat samples were total coliform-negative.

(6) After a system collects a routine sample and before it learns the results of the analysis of that sample, if it collects another routine sample(s) from within five adjacent service connections of the initial sample, and the initial sample, after analysis, is found to contain total coliforms, then the system may count the subsequent sample(s) as a repeat sample instead of as a routine sample.

(7) Results of all routine and repeat samples not invalidated by the State must be included in determining compliance with the MCL for total coliforms in §141.63.

(c) *Invalidation of total coliform samples.* A total coliform-positive sample invalidated under this paragraph (c) does not count towards meeting the minimum monitoring requirements of this section.

(1) The State may invalidate a total coliform-positive sample only if the conditions of paragraph (c)(1) (i), (ii), or (iii) of this section are met.

(i) The laboratory establishes that improper sample analysis caused the total coliform-positive result.

(ii) The State, on the basis of the results of repeat samples collected as required by paragraphs (b) (1) through (4) of this section, determines that the total coliform-positive sample resulted from a domestic or other non-distribution system plumbing problem. The State cannot invalidate a sample on the basis of repeat sample results unless all repeat sample(s) collected at the same tap as the original total coliform-positive sample are also total coliform-positive, and all repeat samples collected within five service connections of the original tap are total coliform-negative (e.g., a State cannot invalidate a total coliform-positive sample on the basis of repeat samples if all the repeat samples are total coliform-negative, or if the public water system has only one service connection).

(iii) The State has substantial grounds to believe that a total coliform-positive result is due to a circumstance or condition which does not reflect water quality in the distribution system. In this case, the system must still collect all repeat samples required under paragraphs (b) (1)–(4) of this section, and use them to determine compliance with the MCL for total coliforms in §141.63. To invalidate a total coliform-positive sample under this paragraph, the decision with the rationale for the decision must be documented in writing, and approved and

signed by the supervisor of the State official who recommended the decision. The State must make this document available to EPA and the public. The written documentation must state the specific cause of the total coliform-positive sample, and what action the system has taken, or will take, to correct this problem. The State may not invalidate a total coliform-positive sample solely on the grounds that all repeat samples are total coliform-negative.

(2) A laboratory must invalidate a total coliform sample (unless total coliforms are detected) if the sample produces a turbid culture in the absence of gas production using an analytical method where gas formation is examined (e.g., the Multiple-Tube Fermentation Technique), produces a turbid culture in the absence of an acid reaction in the Presence-Absence (P–A) Coliform Test, or exhibits confluent growth or produces colonies too numerous to count with an analytical method using a membrane filter (e.g., Membrane Filter Technique). If a laboratory invalidates a sample because of such interference, the system must collect another sample from the same location as the original sample within 24 hours of being notified of the interference problem, and have it analyzed for the presence of total coliforms. The system must continue to re-sample within 24 hours and have the samples analyzed until it obtains a valid result. The State may waive the 24-hour time limit on a case-by-case basis.

(d) *Sanitary surveys.* (1)(i) Public water systems which do not collect five or more routine samples/month must undergo an initial sanitary survey by June 29, 1994, for community public water systems and June 29, 1999, for non-community water systems. Thereafter, systems must undergo another sanitary survey every five years, except that non-community water systems using only protected and disinfected ground water, as defined by the State, must undergo subsequent sanitary surveys at least every ten years after the initial sanitary survey. The State must review the results of each sanitary survey to determine whether the existing monitoring frequency is adequate and what additional measures, if any, the system needs to undertake to improve drinking water quality.

(ii) In conducting a sanitary survey of a system using ground water in a State having an EPA-approved wellhead protection program under section 1428 of the Safe Drinking Water Act, information on sources of contamination within the delineated wellhead protection area that was collected in the course of developing and implementing the program should be considered instead of collecting new information, if the information was collected since the last time the system was subject to a sanitary survey.

(2) Sanitary surveys must be performed by the State or an agent approved by the State. The system is responsible for ensuring the survey takes place.

(e) *Fecal coliforms/Escherichia coli (E. coli) testing.* (1) If any routine or repeat sample is total coliform-positive, the system must analyze that total coliform-positive culture medium to determine if fecal coliforms are present, except that the system may test for *E. coli* in lieu of fecal coliforms. If fecal coliforms or *E. coli* are present, the system must notify the State by the end of the day when the system is notified of the test result, unless the system is notified of the result after the State office is closed, in which case the system must notify the State before the end of the next business day.

(2) The State has the discretion to allow a public water system, on a case-by-case basis, to forgo fecal coliform or *E. coli* testing on a total coliform-positive sample if that system assumes that the total coliform-positive sample is fecal coliform-positive or *E. coli*-positive. Accordingly, the system must notify the State as specified in paragraph (e)(1) of this section and the provisions of § 141.63(b) apply.

(f) *Analytical methodology.* (1) The standard sample volume required for total coliform analysis, regardless of analytical method used, is 100 ml.

(2) Public water systems need only determine the presence or absence of total coliforms; a determination of total coliform density is not required.

(3) Public water systems must conduct total coliform analyses in accordance with one of the analytical methods in the following table.

Organism	Methodology [12]	Citation [1]
Total Coliforms [2].	Total Coliform Fermentation Technique [3,4,5].	9221A, B
	Total Coliform Membrane Filter Technique [6]	9222 A, B, C
	Presence-Absence (P-A) Coliform Test [5,7]	9221
	ONPG-MUG Test [8]	9223
	Colisure Test [9]	
	E*Colite® Test [10]	
	m-ColiBlue24® Test [11]	

The procedures shall be done in accordance with the documents listed below. The incorporation by reference of the following documents listed in footnotes 1, 6, 8, 9, 10 and 11 was approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR Part 51. Copies of the documents may be obtained from the sources listed below. Information regarding obtaining these documents can be obtained from the Safe Drinking Water Hotline at 800–426–4791. Documents may be inspected at EPA's Drinking Water Docket, 1200 Pennsylvania Ave., NW., Washington, DC 20460 (Telephone: 202–260–3027); or at the Office of Federal Register, 800 North Capitol Street, NW, Suite 700, Washington, D.C. 20408.

[1] Methods 9221 A, B; 9222 A, B, C; 9221 D and 9223 are contained in *Standard Methods for the Examination of Water and Wastewater,* 18th edition (1992) and 19th edition (1995) American Public Health Association, 1015 Fifteenth Street NW, Washington, D.C. 20005; either edition may be used.

[2] The time from sample collection to initiation of analysis may not exceed 30 hours. Systems are encouraged but not required to hold samples below 10 °C during transit.

[3] Lactose broth, as commercially available, may be used in lieu of lauryl tryptose broth, if the system conducts at least 25 parallel tests between this medium and lauryl tryptose broth using the water normally tested, and this comparison demonstrates that the false-positive rate and false-negative rate for total coliform, using lactose broth, is less than 10 percent.

[4] If inverted tubes are used to detect gas production, the media should cover these tubes at least one-half to two-thirds after the sample is added.

[5] No requirement exists to run the completed phase on 10 percent of all total coliform-positive confirmed tubes.

[6] MI agar also may be used. Preparation and use of MI agar is set forth in the article, ''New medium for the simultaneous detection of total coliform and *Escherichia coli* in water'' by Brenner, K.P., et al., 1993, Appl. Environ. Microbiol. 59:3534–3544. Also available from the Office of Water Resource Center (RC–4100), 401 M. Street SW, Washington, DC 20460, EPA/600/J–99/225.

[7] Six-times formulation strength may be used if the medium is filter-sterilized rather than autoclaved.

[8] The ONPG-MUG Test is also known as the Autoanalysis Colilert System.

[9] A description of the Colisure Test, Feb 28, 1994, may be obtained from IDEXX Laboratories, Inc., One IDEXX Drive, Westbrook, Maine 04092. The Colisure Test may be read after an incubation time of 24 hours.

[10] A description of the E*Colite® Test, ''Presence/Absence for Coliforms and *E. Coli* in Water,'' Dec 21, 1997, is available from Charm Sciences, Inc., 36 Franklin Street, Malden, MA 02148–4120.

[11] A description of the m-ColiBlue24® Test, Aug 17, 1999, is available from the Hach Company, 100 Dayton Avenue, Ames, IA 50010.

[12] EPA strongly recommends that laboratories evaluate the false-positive and negative rates for the method(s) they use for monitoring total coliforms. EPA also encourages laboratories to establish false-positive and false-negative rates within their own laboratory and sample matrix (drinking water or source water) with the intent that if the method they choose has an unacceptable false-positive or negative rate, another method can be used. The Agency suggests that laboratories perform these studies on a minimum of 5% of all total coliform-positive samples, except for those methods where verification/confirmation is already required, e.g., the M-Endo and LES Endo Membrane Filter Tests, Standard Total Coliform Fermentation Technique, and Presence-Absence Coliform Test. Methods for establishing false-positive and negative-rates may be based on lactose fermentation, the rapid test for β-galactosidase and cytochrome oxidase, multi-test identification systems, or equivalent confirmation tests. False-positive and false-negative information is often available in published studies and/or from the manufacturer(s).

(4) [Reserved]

(5) Public water systems must conduct fecal coliform analysis in accordance with the following procedure. When the MTF Technique or Presence-Absence (PA) Coliform Test is used to test for total coliforms, shake the lactose-positive presumptive tube or P–A vigorously and transfer the growth with a sterile 3-mm loop or sterile applicator stick into brilliant green lactose bile broth and EC medium to determine the presence of total and fecal coliforms, respectively. For EPA-approved analytical methods which use a membrane filter, transfer the total coliform-positive culture by one of the following methods: remove the membrane containing the total coliform colonies from the substrate with a sterile forceps and carefully curl and insert the membrane into a tube of EC medium (the laboratory may first remove a small portion of selected colonies for verification), swab the entire membrane filter surface with a sterile cotton swab and transfer the inoculum to EC medium (do not leave the cotton swab in the EC medium), or inoculate individual total coliform-positive colonies into EC Medium. Gently shake the

inoculated tubes of EC medium to insure adequate mixing and incubate in a waterbath at 44.5 ± 0.2 °C for 24 ± 2 hours. Gas production of any amount in the inner fermentation tube of the EC medium indicates a positive fecal coliform test. The preparation of EC medium is described in Method 9221E (paragraph 1a) in *Standard Methods for the Examination of Water and Wastewater*, 18th edition, 1992 and in the 19th edition, 1995; either edition may be used. Public water systems need only determine the presence or absence of fecal coliforms; a determination of fecal coliform density is not required.

(6) Public water systems must conduct analysis of *Escherichia coli* in accordance with one of the following analytical methods:

(i) EC medium supplemented with 50 μg/ml of 4-methylumbelliferyl-beta-D-glucuronide (MUG) (final concentration). EC medium is described in Method 9221 E as referenced in paragraph (f)(5) of this section. MUG may be added to EC medium before autoclaving. EC medium supplemented with 50 μg/ml of MUG is commercially available. At least 10 ml of EC medium supplemented with MUG must be used. The inner inverted fermentation tube may be omitted. The procedure for transferring a total coliform-positive culture to EC medium supplemented with MUG shall be as specified in paragraph (f)(5) of this section for transferring a total coliform-positive culture to EC medium. Observe fluorescence with an ultraviolet light (366 nm) in the dark after incubating tube at 44.5 ± 0.2 °C for 24 ± 2 hours; or

(ii) Nutrient agar supplemented with 100 μg/ml 4-methylumbelliferyl-beta-D-glucuronide (MUG) (final concentration). Nutrient Agar is described in Method 9221 B (paragraph 3) in *Standard Methods for the Examination of Water and Wastewater*, 18th edition, 1992 and in the 19th edition, 1995; either edition may be used. This test is used to determine if a total coliform-positive sample, as determined by the Membrane Filter Technique or any other method in which a membrane filter is used, contains *E. coli*. Transfer the membrane filter containing a total coliform colony(ies) to nutrient agar supplemented with 100 μg/ml (final concentration) of MUG. After incubating the agar plate at 35 °C for 4 hours, observe the colony(ies) under ultraviolet light (366 nm) in the dark for fluorescence. If fluorescence is visible, *E. coli* are present.

(iii) Minimal Medium ONPG–MUG (MMO–MUG) Test, as set forth in the article ''National Field Evaluation of a Defined Substrate Method for the Simultaneous Detection of Total Coliforms and *Escherichia coli* from Drinking Water: Comparison with Presence-Absence Techniques'' (Edberg et al.), Applied and Environmental Microbiology, Volume 55, pp. 1003–1008, April 1989. (Note: The Autoanalysis Colilert System is an MMO–MUG test). If the MMO–MUG test is total coliform-positive after a 24-hour incubation, test the medium for fluorescence with a 366-nm ultraviolet light (preferably with a 6-watt lamp) in the dark. If fluorescence is observed, the sample is *E. coli*-positive. If fluorescence is questionable (cannot be definitively read) after 24 hours incubation, incubate the culture for an additional four hours (but not to exceed 28 hours total), and again test the medium for fluorescence. The MMO–MUG Test with hepes buffer in lieu of phosphate buffer is the only approved formulation for the detection of *E. coli*.

(iv) The Colisure Test. A description of the Colisure Test may be obtained from the Millipore Corporation, Technical Services Department, 80 Ashby Road, Bedford, MA 01730.

(v) The membrane filter method with MI agar, a description of which is cited in footnote 6 to the table in paragraph (f)(3) of this section.

(vi) E*Colite® Test, a description of which is cited in footnote 10 to the table at paragraph (f)(3) of this section.

(vii) m-ColiBlue24® Test, a description of which is cited in footnote 11 to the table in paragraph (f)(3) of this section.

(7) As an option to paragraph (f)(6)(iii) of this section, a system with a total coliform-positive, MUG-negative, MMO–MUG test may further analyze the culture for the presence of *E. coli* by transferring a 0.1 ml, 28-hour MMO–MUG culture to EC Medium + MUG with a pipet. The formulation and incubation conditions of EC Medium +

MUG, and observation of the results are described in paragraph (f)(6)(i) of this section.

(8) The following materials are incorporated by reference in this section with the approval of the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. Copies of the analytical methods cited in Standard Methods for the Examination of Water and Wastewater (18th and 19th editions) may be obtained from the American Public Health Association *et al.;* 1015 Fifteenth Street NW., Washington, DC 20005. Copies of the methods set forth in *Microbiological Methods for Monitoring the Environment, Water and Wastes* may be obtained from ORD Publications, U.S. EPA, 26 W. Martin Luther King Drive, Cincinnati, Ohio 45268. Copies of the MMO–MUG Test as set forth in the article ''National Field Evaluation of a Defined Substrate Method for the Simultaneous Enumeration of Total Coliforms and *Escherichia coli* from Drinking Water: Comparison with the Standard Multiple Tube Fermentation Method'' (Edberg *et al.*) may be obtained from the American Water Works Association Research Foundation, 6666 West Quincy Avenue, Denver, CO 80235. A description of the Colisure Test may be obtained from the Millipore Corp., Technical Services Department, 80 Ashby Road, Bedford, MA 01730. Copies may be inspected at EPA's Drinking Water Docket; 401 M St., SW.; Washington, DC 20460, or at the Office of the Federal Register; 800 North Capitol Street, NW., suite 700, Washington, DC.

(g) *Response to violation.* (1) A public water system which has exceeded the MCL for total coliforms in §141.63 must report the violation to the State no later than the end of the next business day after it learns of the violation, and notify the public in accordance with subpart Q.

(2) A public water system which has failed to comply with a coliform monitoring requirement, including the sanitary survey requirement, must report the monitoring violation to the State within ten days after the system discovers the violation, and notify the public in accordance with subpart Q.

[54 FR 27562, June 29, 1989, as amended at 54 FR 30001, July 17, 1989; 55 FR 25064, June 19, 1990; 56 FR 642, Jan. 8, 1991; 57 FR 1852, Jan. 15, 1992; 57 FR 24747, June 10, 1992; 59 FR 62466, Dec. 5, 1994; 60 FR 34085, June 29, 1995; 64 FR 67461, Dec. 1, 1999; 65 FR 26022, May 4, 2000]

§141.22 Turbidity sampling and analytical requirements.

The requirements in this section apply to unfiltered systems until December 30, 1991, unless the State has determined prior to that date, in writing pursuant to section 1412(b)(7)(iii), that filtration is required. The requirements in this section apply to filtered systems until June 29, 1993. The requirements in this section apply to unfiltered systems that the State has determined, in writing pursuant to section 1412(b)(7)(C)(iii), must install filtration, until June 29, 1993, or until filtration is installed, whichever is later.

(a) Samples shall be taken by suppliers of water for both community and non-community water systems at a representative entry point(s) to the water distribution system at least once per day, for the purposes of making turbidity measurements to determine compliance with §141.13. If the State determines that a reduced sampling frequency in a non-community will not pose a risk to public health, it can reduce the required sampling frequency. The option of reducing the turbidity frequency shall be permitted only in those public water systems that practice disinfection and which maintain an active residual disinfectant in the distribution system, and in those cases where the State has indicated in writing that no unreasonable risk to health existed under the circumstances of this option. Turbidity measurements shall be made as directed in §141.74(a)(1).

(b) If the result of a turbidity analysis indicates that the maximum allowable limit has been exceeded, the sampling and measurement shall be confirmed by resampling as soon as practicable and preferably within one hour. If the repeat sample confirms that the maximum allowable limit has been exceeded, the supplier of water

Break in Sequence

(16) Polychlorinated biphenyls (PCBs)
(17) Tetrachloroethylene
(18) Toxaphene
(19) Benzo[a]pyrene
(20) Dichloromethane (methylene chloride)
(21) Di(2-ethylhexyl)phthalate
(22) Hexachlorobenzene
(23) 2,3,7,8-TCDD (Dioxin)

(b) MCLGs for the following contaminants are as indicated:

Contaminant	MCLG in mg/l
(1) 1,1-Dichloroethylene	0.007
(2) 1,1,1-Trichloroethane	0.20
(3) para-Dichlorobenzene	0.075
(4) Aldicarb	0.001
(5) Aldicarb sulfoxide	0.001
(6) Aldicarb sulfone	0.001
(7) Atrazine	0.003
(8) Carbofuran	0.04
(9) o-Dichlorobenzene	0.6
(10) cis-1,2-Dichloroethylene	0.07
(11) trans-1,2-Dichloroethylene	0.1
(12) 2,4-D	0.07
(13) Ethylbenzene	0.7
(14) Lindane	0.0002
(15) Methoxychlor	0.04
(16) Monochlorobenzene	0.1
(17) Styrene	0.1
(18) Toluene	1
(19) 2,4,5-TP	0.05
(20) Xylenes (total)	10
(21) Dalapon	0.2
(22) Di(2-ethylhexyl)adipate	.4
(23) Dinoseb	.007
(24) Diquat	.02
(25) Endothall	.1
(26) Endrin	.002
(27) Glyphosate	.7
(28) Hexachlorocyclopentadiene	.05
(29) Oxamyl (Vydate)	.2
(30) Picloram	.5
(31) Simazine	.004
(32) 1,2,4-Trichlorobenzene	.07
(33) 1,1,2-Trichloroethane	.003

[50 FR 46901, Nov. 13, 1985, as amended at 52 FR 20674, June 2, 1987; 52 FR 25716, July 8, 1987; 56 FR 3592, Jan. 30, 1991; 56 FR 30280, July 1, 1991; 57 FR 31846, July 17, 1992]

§ 141.51 Maximum contaminant level goals for inorganic contaminants.

(a) [Reserved]

(b) MCLGs for the following contaminants are as indicated:

Contaminant	MCLG (mg/l)
Antimony	0.006
Arsenic	zero[1]
Asbestos	7 Million fibers/liter (longer than 10 μm).
Barium	2
Beryllium	.004
Cadmium	0.005
Chromium	0.1
Copper	1.3
Cyanide (as free Cyanide)	.2
Fluoride	4.0
Lead	zero
Mercury	0.002
Nitrate	10 (as Nitrogen).
Nitrite	1 (as Nitrogen).
Total Nitrate+Nitrite	10 (as Nitrogen).
Selenium	0.05
Thallium	.0005

[1] This value for arsenic is effective January 23, 2006. Until then, there is no MCLG.

[50 FR 47155, Nov. 14, 1985, as amended at 52 FR 20674, June 2, 1987; 56 FR 3593, Jan. 30, 1991; 56 FR 26548, June 7, 1991; 56 FR 30280, July 1, 1991; 57 FR 31846, July 17, 1992; 60 FR 33932, June 29, 1995; 66 FR 7063, Jan. 22, 2001]

§ 141.52 Maximum contaminant level goals for microbiological contaminants.

MCLGs for the following contaminants are as indicated:

Contaminant	MCLG
(1) *Giardia lamblia*	zero
(2) Viruses	zero
(3) *Legionella*	zero
(4) Total coliforms (including fecal coliforms and *Escherichia coli*).	zero.
(5) *Cryptosporidium*	zero.

[54 FR 27527, 27566, June 29, 1989; 55 FR 25064, June 19, 1990; 63 FR 69515, Dec. 16, 1998]

§ 141.53 Maximum contaminant level goals for disinfection byproducts.

MCLGs for the following disinfection byproducts are as indicated:

Disinfection byproduct	MCLG (mg/L)
Bromodichloromethane	Zero
Bromoform	Zero
Bromate	Zero
Dichloroacetic acid	Zero
Trichloroacetic acid	0.3
Chlorite	0.8
Dibromochloromethane	0.06

[63 FR 69465, Dec. 16, 1998, as amended at 65 FR 34405, May 30, 2000]

§ 141.54 Maximum residual disinfectant level goals for disinfectants.

MRDLGs for disinfectants are as follows:

Disinfectant residual	MRDLG(mg/L)
Chlorine	4 (as Cl_2).
Chloramines	4 (as Cl_2).

Break in Sequence

BAT FOR INORGANIC COMPOUNDS LISTED IN SECTION 141.62(B)

Chemical Name	BAT(s)
Asbestos	2,3,8
Barium	5,6,7,9
Beryllium	1,2,5,6,7
Cadmium	2,5,6,7
Chromium	2,5,6[2],7
Cyanide	5,7,10
Mercury	2[1],4,6[1],7[1]
Nickel	5,6,7
Nitrate	5,7,9
Nitrite	5,7
Selenium	1,2[3],6,7,9
Thallium	1,5

[1] BAT only if influent Hg concentrations ≤10µg/1.
[2] BAT for Chromium III only.
[3] BAT for Selenium IV only.
[4] BATs for Arsenic V. Pre-oxidation may be required to convert Arsenic III to Arsenic V.
[5] To obtain high removals, iron to arsenic ratio must be at least 20:1.

Key to BATS in Table

1=Activated Alumina
2 = Coagulation/Filtration (not BAT for systems < 500 service connections)
2=Coagulation/Filtration
3=Direct and Diatomite Filtration
4=Granular Activated Carbon
5=Ion Exchange
6 = Lime Softening (not BAT for systems < 500 service connections)
7=Reverse Osmosis
8=Corrosion Control
9=Electrodialysis
10=Chlorine
11=Ultraviolet
12 = Oxidation/Filtration

(d) The Administrator, pursuant to section 1412 of the Act, hereby identifies in the following table the affordable technology, treatment technique, or other means available to systems serving 10,000 persons or fewer for achieving compliance with the maximum contaminant level for arsenic:

SMALL SYSTEM COMPLIANCE TECHNOLOGIES (SSCTS)[1] FOR ARSENIC[2]

Small system compliance technology	Affordable for listed small system categories[3]
Activated Alumina (centralized).	All size categories.
Activated Alumina (Point-of-Use)[4].	All size categories.
Coagulation/Filtration[5]	501–3,300, 3,301–10,000.
Coagulation-assisted Microfiltration.	501–3,300, 3,301–10,000.
Electrodialysis reversal[6]	501–3,300, 3,301–10,000.
Enhanced coagulation/filtration.	All size categories
Enhanced lime softening (pH> 10.5).	All size categories.
Ion Exchange	All size categories.
Lime Softening[5]	501–3,300, 3,301–10,000.
Oxidation/Filtration[7]	All size categories.
Reverse Osmosis (centralized)[6].	501–3,300, 3,301–10,000.
Reverse Osmosis (Point-of-Use)[4].	All size categories.

[1] Section 1412(b)(4)(E)(ii) of SDWA specifies that SSCTs must be affordable and technically feasible for small systems.
[2] SSCTs for Arsenic V. Pre-oxidation may be required to convert Arsenic III to Arsenic V.
[3] The Act (ibid.) specifies three categories of small systems: (i) those serving 25 or more, but fewer than 501, (ii) those serving more than 500, but fewer than 3,301, and (iii) those serving more than 3,300, but fewer than 10,001.
[4] When POU or POE devices are used for compliance, programs to ensure proper long-term operation, maintenance, and monitoring must be provided by the water system to ensure adequate performance.
[5] Unlikely to be installed solely for arsenic removal. May require pH adjustment to optimal range if high removals are needed.
[6] Technologies reject a large volume of water—may not be appropriate for areas where water quantity may be an issue.
[7] To obtain high removals, iron to arsenic ratio must be at least 20:1.

[56 FR 3594, Jan. 30, 1991, as amended at 56 FR 30280, July 1, 1991; 57 FR 31847, July 17, 1992; 59 FR 34325, July 1, 1994; 60 FR 33932, June 29, 1995; 66 FR 7063, Jan. 22, 2001]

§ 141.63 Maximum contaminant levels (MCLs) for microbiological contaminants.

(a) The MCL is based on the presence or absence of total coliforms in a sample, rather than coliform density.

(1) For a system which collects at least 40 samples per month, if no more than 5.0 percent of the samples collected during a month are total coliform-positive, the system is in compliance with the MCL for total coliforms.

(2) For a system which collects fewer than 40 samples/month, if no more than one sample collected during a month is total coliform-positive, the system is in compliance with the MCL for total coliforms.

(b) Any fecal coliform-positive repeat sample or *E. coli*-positive repeat sample, or any total coliform-positive repeat sample following a fecal coliform-positive or *E. coli*-positive routine sample constitutes a violation of the MCL for total coliforms. For purposes of the public notification requirements in subpart Q, this is a violation that may pose an acute risk to health.

(c) A public water system must determine compliance with the MCL for total coliforms in paragraphs (a) and (b) of this section for each month in

which it is required to monitor for total coliforms.

(d) The Administrator, pursuant to section 1412 of the Act, hereby identifies the following as the best technology, treatment techniques, or other means available for achieving compliance with the maximum contaminant level for total coliforms in paragraphs (a) and (b) of this section:

(1) Protection of wells from contamination by coliforms by appropriate placement and construction;

(2) Maintenance of a disinfectant residual throughout the distribution system;

(3) Proper maintenance of the distribution system including appropriate pipe replacement and repair procedures, main flushing programs, proper operation and maintenance of storage tanks and reservoirs, and continual maintenance of positive water pressure in all parts of the distribution system;

(4) Filtration and/or disinfection of surface water, as described in subpart H, or disinfection of ground water using strong oxidants such as chlorine, chlorine dioxide, or ozone; and

(5) For systems using ground water, compliance with the requirements of an EPA-approved State Wellhead Protection Program developed and implemented under section 1428 of the SDWA.

[54 FR 27566, June 29, 1989; 55 FR 25064, June 19, 1990, as amended at 65 FR 26022, May 4, 2000]

§ 141.64 Maximum contaminant levels for disinfection byproducts.

(a) The maximum contaminant levels (MCLs) for disinfection byproducts are as follows:

Disinfection byproduct	MCL (mg/L)
Total trihalomethanes (TTHM)	0.080
Haloacetic acids (five) (HAA5)	0.060
Bromate	0.010
Chlorite	1.0

(b) *Compliance dates.* (1) *CWSs and NTNCWSs.* Subpart H systems serving 10,000 or more persons must comply with this section beginning January 1, 2002. Subpart H systems serving fewer than 10,000 persons and systems using only ground water not under the direct influence of surface water must comply with this section beginning January 1, 2004.

(2) A system that is installing GAC or membrane technology to comply with this section may apply to the State for an extension of up to 24 months past the dates in paragraphs (b)(1) of this section, but not beyond December 31, 2003. In granting the extension, States must set a schedule for compliance and may specify any interim measures that the system must take. Failure to meet the schedule or interim treatment requirements constitutes a violation of a National Primary Drinking Water Regulation.

(c) The Administrator, pursuant to Section 1412 of the Act, hereby identifies the following as the best technology, treatment techniques, or other means available for achieving compliance with the maximum contaminant levels for disinfection byproducts identified in paragraph (a) of this section:

Disinfection byproduct	Best available technology
TTHM	Enhanced coagulation or enhanced softening or GAC10, with chlorine as the primary and residual disinfectant
HAA5	Enhanced coagulation or enhanced softening or GAC10, with chlorine as the primary and residual disinfectant.
Bromate	Control of ozone treatment process to reduce production of bromate.
Chlorite	Control of treatment processes to reduce disinfectant demand and control of disinfection treatment processes to reduce disinfectant levels.

[63 FR 69465, Dec. 16, 1998, as amended at 66 FR 3776, Jan. 16, 2001]

§ 141.65 Maximum residual disinfectant levels.

(a) Maximum residual disinfectant levels (MRDLs) are as follows:

Disinfectant residual	MRDL (mg/L)
Chlorine	4.0 (as Cl_2).
Chloramines	4.0 (as Cl_2).
Chlorine dioxide	0.8 (as ClO_2).

(b) *Compliance dates.* (1) *CWSs and NTNCWSs.* Subpart H systems serving 10,000 or more persons must comply with this section beginning January 1, 2002. Subpart H systems serving fewer than 10,000 persons and systems using only ground water not under the direct influence of surface water must comply

Break in Sequence

at least 10,000 people must meet the requirements for other filtration technologies in §141.173(b). Beginning January 14, 2005, systems serving fewer than 10,000 people must meet the requirements for other filtration technologies in §141.550 through 141.553.

[54 FR 27527, June 29, 1989, as amended at 63 FR 69516, Dec. 16, 1998; 66 FR 3776, Jan. 16, 2001; 67 FR 1836, Jan. 14, 2002]

§141.74 Analytical and monitoring requirements.

(a) *Analytical requirements.* Only the analytical method(s) specified in this paragraph, or otherwise approved by EPA, may be used to demonstrate compliance with §§141.71, 141.72 and 141.73. Measurements for pH, turbidity, temperature and residual disinfectant concentrations must be conducted by a person approved by the State. Measurement for total coliforms, fecal coliforms and HPC must be conducted by a laboratory certified by the State or EPA to do such analysis. Until laboratory certification criteria are developed for the analysis of fecal coliforms and HPC, any laboratory certified for total coliforms analysis by the State or EPA is deemed certified for fecal coliforms and HPC analysis. The following procedures shall be conducted in accordance with the publications listed in the following section. This incorporation by reference was approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. Copies of the methods published in *Standard Methods for the Examination of Water and Wastewater* may be obtained from the American Public Health Association et al., 1015 Fifteenth Street, NW., Washington, DC 20005; copies of the Minimal Medium ONPG–MUG Method as set forth in the article ''National Field Evaluation of a Defined Substrate Method for the Simultaneous Enumeration of Total Coliforms and *Escherichia coli* from Drinking Water: Comparison with the Standard Multiple Tube Fermentation Method'' (Edberg et al.), Applied and Environmental Microbiology, Volume 54, pp. 1595–1601, June 1988 (as amended under Erratum, Applied and Environmental Microbiology, Volume 54, p. 3197, December, 1988), may be obtained from the American Water Works Association Research Foundation, 6666 West Quincy Avenue, Denver, Colorado, 80235; and copies of the Indigo Method as set forth in the article ''Determination of Ozone in Water by the Indigo Method'' (Bader and Hoigne), may be obtained from Ozone Science & Engineering, Pergamon Press Ltd., Fairview Park, Elmsford, New York 10523. Copies may be inspected at the U.S. Environmental Protection Agency, Room EB15, 401 M St., SW., Washington, DC 20460 or at the Office of the Federal Register, 800 North Capitol Street, NW., suite 700, Washington, DC.

(1) Public water systems must conduct analysis of pH and temperature in accordance with one of the methods listed at §141.23(k)(1). Public water systems must conduct analysis of total coliforms, fecal coliforms, heterotrophic bacteria, and turbidity in accordance with one of the following analytical methods and by using analytical test procedures contained in *Technical Notes on Drinking Water Methods,* EPA–600/R–94–173, October 1994, which is available at NTIS PB95–104766.

Organism	Methodology	Citation [1]
Total Coliform [2]	Total Coliform Fermentation Technique [3,4,5].	9221 A, B, C
	Total Coliform Membrane Filter Technique [6].	9222 A, B, C
	ONPG–MUG Test [7].	9223
Fecal Coliforms [2] ...	Fecal Coliform Procedure [8].	9221 E
	Fecal Coliform Filter Procedure.	9222 D
Heterotrophic bacteria [2].	Pour Plate Method	9215 B
Turbidity	Nephelometric Method.	2130 B
	Nephelometric Method.	180.1 [9]
	Great Lakes Instruments.	Method 2 [10]

The procedures shall be done in accordance with the documents listed below. The incorporation by reference of the following documents listed in footnotes 1, 6, 7, 9 and 10 was approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. Copies of the documents may be obtained from the sources listed below. Information regarding obtaining these documents can be obtained from the Safe Drinking Water Hotline at 800–426–4791. Documents may be inspected at EPA's Drinking Water Docket, 1200 Pennsylvania Ave., NW., Washington, DC 20460 (Telephone: 202–260–3027); or at the Office of the Federal Register, 800 North Capitol Street, NW, Suite 700, Washington, D.C. 20408.

[1] Except where noted, all methods refer to *Standard Methods for the Examination of Water and Wastewater,* 18th edition, 1992 and 19th edition, 1995, American Public Health Association, 1015 Fifteenth Street NW, Washington, D.C. 20005; either edition may be used.

[2] The time from sample collection to initiation of analysis may not exceed 8 hours. Systems must hold samples below 10°C during transit.

[3] Lactose broth, as commercially available, may be used in lieu of lauryl tryptose broth, if the system conducts at least 25 parallel tests between this medium and lauryl tryptose broth using the water normally tested, and this comparison demonstrates that the false-positive rate and false-negative rate for total coliform, using lactose broth, is less than 10 percent.

[4] Media should cover inverted tubes at least one-half to two-thirds after the sample is added.

[5] No requirement exists to run the completed phase on 10 percent of all total coliform-positive confirmed tubes.

[6] MI agar also may be used. Preparation and use of MI agar is set forth in the article, ''New medium for the simultaneous detection of total coliform and Escherichia coli in water'' by Brenner, K.P., et al., 1993, Appl. Environ. Microbiol. 59:3534–3544. Also available from the Office of Water Resource Center (RC–4100), 1200 Pennsylvania Ave., NW., Washington, DC 20460, EPA 600/J–99/225.

[7] The ONPG–MUG Test is also known as the Autoanalysis Colilert System.

[8] A–1 Broth may be held up to three months in a tightly closed screw cap tube at 4 °C.

[9] ''Methods for the Determination of Inorganic Substances in Environmental Samples'', EPA/600/R–93/100, August 1993. Available at NTIS, PB94–121811.

[10] GLI Method 2, ''Turbidity'', November 2, 1992, Great Lakes Instruments, Inc., 8855 North 55th Street, Milwaukee, Wisconsin 53223.

(2) Public water systems must measure residual disinfectant concentrations with one of the analytical methods in the following table. The methods are contained in both the 18th and 19th editions of *Standard Methods for the Examination of Water and Wastewater*, 1992 and 1995; either edition may be used. Other analytical test procedures are contained *in Technical Notes on Drinking Water Methods*, EPA–600/R–94–173, October 1994, which is available at NTIS PB95–104766. If approved by the State, residual disinfectant concentrations for free chlorine and combined chlorine also may be measured by using DPD colorimetric test kits. Free and total chlorine residuals may be measured continuously by adapting a specified chlorine residual method for use with a continuous monitoring instrument provided the chemistry, accuracy, and precision remain same. Instruments used for continuous monitoring must be calibrated with a grab sample measurement at least every five days, or with a protocol approved by the State.

Residual	Methodology	Methods
Free Chlorine.	Amperometric Titration	4500–Cl D
	DPD Ferrous Titrimetric.	4500–Cl F
	DPD Colorimetric	4500–Cl G
	Syringaldazine (FACTS).	4500–Cl H
Total Chlorine.	Amperometric Titration	4500–Cl D
	Amperometric Titration (low level measurement).	4500–Cl E
	DPD Ferrous Titrimetric.	4500–Cl F
	DPD Colorimetric	4500–Cl G
	Iodometric Electrode	4500–Cl I
Chlorine Dioxide.	Amperometric Titration	4500–ClO_2 C
	DPD Method	4500–ClO_2 D
	Amperometric Titration	4500–ClO_2 E
Ozone	Indigo Method	4500–O_3 B

(b) *Monitoring requirements for systems that do not provide filtration.* A public water system that uses a surface water source and does not provide filtration treatment must begin monitoring, as specified in this paragraph (b), beginning December 31, 1990, unless the State has determined that filtration is required in writing pursuant to §1412(b)(7)(C)(iii), in which case the State may specify alternative monitoring requirements, as appropriate, until filtration is in place. A public water system that uses a ground water source under the direct influence of surface water and does not provide filtration treatment must begin monitoring as specified in this paragraph (b) beginning December 31, 1990, or 6 months after the State determines that the ground water source is under the direct influence of surface water, whichever is later, unless the State has determined that filtration is required in writing pursuant to §1412(b)(7)(C)(iii), in which case the State may specify alternative monitoring requirements, as appropriate, until filtration is in place.

(1) Fecal coliform or total coliform density measurements as required by §141.71(a)(1) must be performed on representative source water samples immediately prior to the first or only point of disinfectant application. The system must sample for fecal or total coliforms at the following minimum frequency each week the system serves water to the public:

System size (persons served)	Samples/week[1]
≤500	1
501 to 3,300	2
3,301 to 10,000	3
10,001 to 25,000	4
>25,000	5

[1] Must be taken on separate days.

Also, one fecal or total coliform density measurement must be made every day the system serves water to the public and the turbidity of the source water exceeds 1 NTU (these samples count towards the weekly coliform sampling requirement) unless the State determines that the system, for logistical reasons outside the system's control, cannot have the sample analyzed within 30 hours of collection.

(2) Turbidity measurements as required by §141.71(a)(2) must be performed on representative grab samples of source water immediately prior to the first or only point of disinfectant application every four hours (or more frequently) that the system serves water to the public. A public water system may substitute continuous turbidity monitoring for grab sample monitoring if it validates the continuous measurement for accuracy on a regular basis using a protocol approved by the State.

(3) The total inactivation ratio for each day that the system is in operation must be determined based on the $CT_{99.9}$ values in tables 1.1–1.6, 2.1, and 3.1 of this section, as appropriate. The parameters necessary to determine the total inactivation ratio must be monitored as follows:

(i) The temperature of the disinfected water must be measured at least once per day at each residual disinfectant concentration sampling point.

(ii) If the system uses chlorine, the pH of the disinfected water must be measured at least once per day at each chlorine residual disinfectant concentration sampling point.

(iii) The disinfectant contact time(s) (''T'') must be determined for each day during peak hourly flow.

(iv) The residual disinfectant concentration(s) (''C'') of the water before or at the first customer must be measured each day during peak hourly flow.

(v) If a system uses a disinfectant other than chlorine, the system may demonstrate to the State, through the use of a State-approved protocol for on-site disinfection challenge studies or other information satisfactory to the State, that $CT_{99.9}$ values other than those specified in tables 2.1 and 3.1 in this section other operational parameters are adequate to demonstrate that the system is achieving the minimum inactivation rates required by §141.72(a)(1).

TABLE 1.1—CT VALUES ($CT_{99.9}$) FOR 99.9 PERCENT INACTIVATION OF GIARDIA LAMBLIA CYSTS BY FREE CHLORINE AT 0.5 °C OR LOWER [1]

Residual (mg/l)	pH						
	≦6.0	6.5	7.0	7.5	8.0	8.5	≦9.0
≦0.4 ..	137	163	195	237	277	329	390
0.6	141	168	200	239	286	342	407
0.8	145	172	205	246	295	354	422
1.0	148	176	210	253	304	365	437
1.2	152	180	215	259	313	376	451
1.4	155	184	221	266	321	387	464
1.6	157	189	226	273	329	397	477
1.8	162	193	231	279	338	407	489
2.0	165	197	236	286	346	417	500
2.2	169	201	242	297	353	426	511
2.4	172	205	247	298	361	435	522
2.6	175	209	252	304	368	444	533
2.8	178	213	257	310	375	452	543
3.0	181	217	261	316	382	460	552

[1] These CT values achieve greater than a 99.99 percent inactivation of viruses. CT values between the indicated pH values may be determined by linear interpolation. CT values between the indicated temperatures of different tables may be determined by linear interpolation. If no interpolation is used, use the $CT_{99.9}$ value at the lower temperature and at the higher pH.

TABLE 1.2—CT VALUES ($CT_{99.9}$) FOR 99.9 PERCENT INACTIVATION OF GIARDIA LAMBLIA CYSTS BY FREE CHLORINE AT 5.0 °C[1]

Free residual (mg/l)	pH						
	≦6.0	6.5	7.0	7.5	8.0	8.5	≦9.0
≦0.4 ..	97	117	139	166	198	236	279
0.6 ..	100	120	143	171	204	244	291
0.8 ..	103	122	146	175	210	252	301
1.0 ..	105	125	149	179	216	260	312
1.2 ..	107	127	152	183	221	267	320
1.4 ..	109	130	155	187	227	274	329
1.6 ..	111	132	158	192	232	281	337
1.8 ..	114	135	162	196	238	287	345
2.0 ..	116	138	165	200	243	294	353
2.2 ..	118	140	169	204	248	300	361
2.4 ..	120	143	172	209	253	306	368
2.6 ..	122	146	175	213	258	312	375
2.8 ..	124	148	178	217	263	318	382
3.0 ..	126	151	182	221	268	324	389

[1] These CT values achieve greater than a 99.99 percent inactivation of viruses. CT values between the indicated pH values may be determined by linear interpolation. CT values between the indicated temperatures of different tables may be determined by linear interpolation. If no interpolation is used, use the $CT_{99.9}$ value at the lower temperature, and at the higher pH.

TABLE 1.3—CT VALUES (CT $_{99.9}$) FOR 99.9 PERCENT INACTIVATION OF GIARDIA LAMBLIA CYSTS BY FREE CHLORINE AT 10.0 °C[1]

Free residual (mg/l)	pH						
	≤6.0	6.5	7.0	7.5	8.0	8.5	≤9.0
≤0.4 ..	73	88	104	125	149	177	209
0.6 ..	75	90	107	128	153	183	218
0.8 ..	78	92	110	131	158	189	226
1.0 ..	79	94	112	134	162	195	234
1.2 ..	80	95	114	137	166	200	240
1.4 ..	82	98	116	140	170	206	247
1.6 ..	83	99	119	144	174	211	253
1.8 ..	86	101	122	147	179	215	259
2.0 ..	87	104	124	150	182	221	265
2.2 ..	89	105	127	153	186	225	271
2.4 ..	90	107	129	157	190	230	276
2.6 ..	92	110	131	160	194	234	281
2.8 ..	93	111	134	163	197	239	287
3.0 ..	95	113	137	166	201	243	292

[1] These CT values achieve greater than a 99.99 percent inactivation of viruses. CT values between the indicated pH values may be determined by linear interpolation. CT values between the indicated temperatures of different tables may be determined by linear interpolation. If no interpolation is used, use the $CT_{99.9}$ value at the lower temperature, and at the higher pH.

TABLE 1.4—CT VALUES (CT $_{99.9}$) FOR 99.9 PERCENT INACTIVATION OF GIARDIA LAMBLIA CYSTS BY FREE CHLORINE AT 15.0 °C[1]

Free residual (mg/l)	pH						
	≤6.0	6.5	7.0	7.5	8.0	8.5	≤9.0
≤0.4 ..	49	59	70	83	99	118	140
0.6 ..	50	60	72	86	102	122	146
0.8 ..	52	61	73	88	105	126	151
1.0 ..	53	63	75	90	108	130	156
1.2 ..	54	64	76	92	111	134	160
1.4 ..	55	65	78	94	114	137	165
1.6 ..	56	66	79	96	116	141	169
1.8 ..	57	68	81	98	119	144	173
2.0 ..	58	69	83	100	122	147	177
2.2 ..	59	70	85	102	124	150	181
2.4 ..	60	72	86	105	127	153	184
2.6 ..	61	73	88	107	129	156	188
2.8 ..	62	74	89	109	132	159	191
3.0 ..	63	76	91	111	134	162	195

[1] These CT values achieve greater than a 99.99 percent inactivation of viruses. CT values between the indicated pH values may be determined by linear interpolation. CT values between the indicated temperatures of different tables may be determined by linear interpolation. If no interpolation is used, use the $CT_{99.9}$ value at the lower temperature, and at the higher pH.

TABLE 1.5—CT VALUES ($CT_{99.9}$) FOR 99.9 PERCENT INACTIVATION OF GIARDIA LAMBLIA CYSTS BY FREE CHLORINE AT 20 °C[1]

Free residual (mg/l)	pH						
	≤ 6.0	6.5	7.0	7.5	8.0	8.5	≤ 9.0
≤ 0.4	36	44	52	62	74	89	105
0.6	38	45	54	64	77	92	109
0.8	39	46	55	66	79	95	113
1.0	39	47	56	67	81	98	117
1.2	40	48	57	69	83	100	120
1.4	41	49	58	70	85	103	123
1.6	42	50	59	72	87	105	126
1.8	43	51	61	74	89	108	129
2.0	44	52	62	75	91	110	132
2.2	44	53	63	77	93	113	135
2.4	45	54	65	78	95	115	138
2.6	46	55	66	80	97	117	141
2.8	47	56	67	81	99	119	143
3.0	47	57	68	83	101	122	146

[1] These CT values achieve greater than a 99.99 percent inactivation of viruses. CT values between the indicated pH values may be determined by linear interpolation. CT values between the indicated temperatures of different tables may be determined by linear interpolation. If no interpolation is used, use the $CT_{99.9}$ value at the lower temperature, and at the higher pH.

TABLE 1.6—CT VALUES ($CT_{99.9}$) FOR 99.9 PERCENT INACTIVATION OF GIARDIA LAMBLIA CYSTS BY FREE CHLORINE AT 25 °C[1] AND HIGHER

Free residual (mg/l)	pH						
	≤ 6.0	6.5	7.0	7.5	8.0	8.5	≤ 9.0
≤ 0.4	24	29	35	42	50	59	70
0.6	25	30	36	43	51	61	73
0.8	26	31	37	44	53	63	75
1.0	26	31	37	45	54	65	78
1.2	27	32	38	46	55	67	80
1.4	27	33	39	47	57	69	82
1.6	28	33	40	48	58	70	84
1.8	29	34	41	49	60	72	86
2.0	29	35	41	50	61	74	88
2.2	30	35	42	51	62	75	90
2.4	30	36	43	52	63	77	92
2.6	31	37	44	53	65	78	94
2.8	31	37	45	54	66	80	96
3.0	32	38	46	55	67	81	97

[1] These CT values achieve greater than a 99.99 percent inactivation of viruses. CT values between the indicated pH values may be determined by linear interpolation. CT values between the indicated temperatures of different tables may be determined by linear interpolation. If no interpolation is used, use the $CT_{99.9}$ value at the lower temperature, and at the higher pH.

TABLE 2.1—CT VALUES ($CT_{99.9}$) FOR 99.9 PERCENT INACTIVATION OF GIARDIA LAMBLIA CYSTS BY CHLORINE DIOXIDE AND OZONE[1]

	Temperature					
	< 1 °C	5 °C	10 °C	15 °C	20 °C	≥ 25 °C
Chlorine dioxide	63	26	23	19	15	11
Ozone	2.9	1.9	1.4	0.95	0.72	0.48

[1] These CT values achieve greater than 99.99 percent inactivation of viruses. CT values between the indicated temperatures may be determined by linear interpolation. If no interpolation is used, use the $CT_{99.9}$ value at the lower temperature for determining $CT_{99.9}$ values between indicated temperatures.

TABLE 3.1—CT VALUES ($CT_{99.9}$) FOR 99.9 PERCENT INACTIVATION OF GIARDIA LAMBLIA CYSTS BY CHLORAMINES[1]

Temperature					
< 1 °C	5 °C	10 °C	15 °C	20 °C	25 °C
3,800	2,200	1,850	1,500	1,100	750

[1] These values are for pH values of 6 to 9. These CT values may be assumed to achieve greater than 99.99 percent inactivation of viruses only if chlorine is added and mixed in the water prior to the addition of ammonia. If this condition is not met, the system must demonstrate, based on on-site studies or other information, as approved by the State, that the system is achieving at least 99.99 percent inactivation of viruses. CT values between the indicated temperatures may be determined by linear interpolation. If no interpolation is used, use the $CT_{99.9}$ value at the lower temperature for determining $CT_{99.9}$ values between indicated temperatures.

(4) The total inactivation ratio must be calculated as follows:

(i) If the system uses only one point of disinfectant application, the system may determine the total inactivation ratio based on either of the following two methods:

(A) One inactivation ratio ($CTcalc/CT_{99.9}$) is determined before or at the first customer during peak hourly flow and if the $CTcalc/CT_{99.9} \geqq 1.0$, the 99.9 percent *Giardia lamblia* inactivation requirement has been achieved; or

(B) Successive $CTcalc/CT_{99.9}$ values, representing sequential inactivation ratios, are determined between the point of disinfectant application and a point before or at the first customer during peak hourly flow. Under this alternative, the following method must be used to calculate the total inactivation ratio:

(1) Determine $\frac{CTcalc}{CT_{99.9}}$ for each sequence.

(2) Add the $\frac{CTcalc}{CT_{99.9}}$ values together $\left(\sum \frac{(CTcalc)}{CT_{99.9}}\right)$

(3) If $\sum \left(\frac{CTcalc}{CT_{99.9}}\right) \geq 1.0$, the 99.9 percent *Giardia lamblia* inactivation requirement has been achieved.

(ii) If the system uses more than one point of disinfectant application before or at the first customer, the system must determine the CT value of each disinfection sequence immediately prior to the next point of disinfectant application during peak hourly flow. The $CTcalc/CT_{99.9}$ value of each sequence and

$$\sum \frac{CTcalc}{CT_{99.9}}$$

must be calculated using the method in paragraph (b)(4)(i)(B) of this section to determine if the system is in compliance with §142.72(a).

(iii) Although not required, the total percent inactivation for a system with one or more points of residual disinfectant concentration monitoring may be calculated by solving the following equation:

$$\text{Percent inactivation} = 100 - \frac{100}{10^{z}}$$

$$\text{where } z = 3 \times \sum \left(\frac{CTcalc}{CT_{99.9}}\right)$$

(5) The residual disinfectant concentration of the water entering the distribution system must be monitored continuously, and the lowest value must be recorded each day, except that if there is a failure in the continuous monitoring equipment, grab sampling every 4 hours may be conducted in lieu of continuous monitoring, but for no more than 5 working days following the failure of the equipment, and systems serving 3,300 or fewer persons may take grab samples in lieu of providing continuous monitoring on an ongoing

basis at the frequencies prescribed below:

System size by population	Samples/day[1]
<500	1
501 to 1,000	2
1,001 to 2,500	3
2,501 to 3,300	4

[1] The day's samples cannot be taken at the same time. The sampling intervals are subject to State review and approval.

If at any time the residual disinfectant concentration falls below 0.2 mg/l in a system using grab sampling in lieu of continuous monitoring, the system must take a grab sample every 4 hours until the residual concentration is equal to or greater than 0.2 mg/l.

(6)(i) The residual disinfectant concentration must be measured at least at the same points in the distribution system and at the same time as total coliforms are sampled, as specified in §141.21, except that the State may allow a public water system which uses both a surface water source or a ground water source under direct influence of surface water, and a ground water source, to take disinfectant residual samples at points other than the total coliform sampling points if the State determines that such points are more representative of treated (disinfected) water quality within the distribution system. Heterotrophic bacteria, measured as heterotrophic plate count (HPC) as specified in paragraph (a)(3) of this section, may be measured in lieu of residual disinfectant concentration.

(ii) If the State determines, based on site-specific considerations, that a system has no means for having a sample transported and analyzed for HPC by a certified laboratory under the requisite time and temperature conditions specified by paragraph (a)(3) of this section and that the system is providing adequate disinfection in the distribution system, the requirements of paragraph (b)(6)(i) of this section do not apply to that system.

(c) *Monitoring requirements for systems using filtration treatment.* A public water system that uses a surface water source or a ground water source under the influence of surface water and provides filtration treatment must monitor in accordance with this paragraph (c) beginning June 29, 1993, or when filtration is installed, whichever is later.

(1) Turbidity measurements as required by §141.73 must be performed on representative samples of the system's filtered water every four hours (or more frequently) that the system serves water to the public. A public water system may substitute continuous turbidity monitoring for grab sample monitoring if it validates the continuous measurement for accuracy on a regular basis using a protocol approved by the State. For any systems using slow sand filtration or filtration treatment other than conventional treatment, direct filtration, or diatomaceous earth filtration, the State may reduce the sampling frequency to once per day if it determines that less frequent monitoring is sufficient to indicate effective filtration performance. For systems serving 500 or fewer persons, the State may reduce the turbidity sampling frequency to once per day, regardless of the type of filtration treatment used, if the State determines that less frequent monitoring is sufficient to indicate effective filtration performance.

(2) The residual disinfectant concentration of the water entering the distribution system must be monitored continuously, and the lowest value must be recorded each day, except that if there is a failure in the continuous monitoring equipment, grab sampling every 4 hours may be conducted in lieu of continuous monitoring, but for no more than 5 working days following the failure of the equipment, and systems serving 3,300 or fewer persons may take grab samples in lieu of providing continuous monitoring on an ongoing basis at the frequencies each day prescribed below:

System size by population	Samples/day[1]
±500	1
501 to 1,000	2
1,001 to 2,500	3
2,501 to 3,300	4

[1] The day's samples cannot be taken at the same time. The sampling intervals are subject to State review and approval.

If at any time the residual disinfectant concentration falls below 0.2 mg/l in a system using grab sampling in lieu of continuous monitoring, the system must take a grab sample every 4 hours

until the residual disinfectant concentration is equal to or greater than 0.2 mg/l.

(3)(i) The residual disinfectant concentration must be measured at least at the same points in the distribution system and at the same time as total coliforms are sampled, as specified in §141.21, except that the State may allow a public water system which uses both a surface water source or a ground water source under direct influence of surface water, and a ground water source to take disinfectant residual samples at points other than the total coliform sampling points if the State determines that such points are more representative of treated (disinfected) water quality within the distribution system. Heterotrophic bacteria, measured as heterotrophic plate count (HPC) as specified in paragraph (a)(3) of this section, may be measured in lieu of residual disinfectant concentration.

(ii) If the State determines, based on site-specific considerations, that a system has no means for having a sample transported and analyzed for HPC by a certified laboratory under the requisite time and temperature conditions specified by paragraph (a)(3) of this section and that the system is providing adequate disinfection in the distribution system, the requirements of paragraph (c)(3)(i) of this section do not apply to that system.

[54 FR 27527, June 29, 1989, as amended at 59 FR 62470, Dec. 5, 1994; 60 FR 34086, June 29, 1995; 64 FR 67465, Dec. 1, 1999]

§141.75 Reporting and recordkeeping requirements.

(a) A public water system that uses a surface water source and does not provide filtration treatment must report monthly to the State the information specified in this paragraph (a) beginning December 31, 1990, unless the State has determined that filtration is required in writing pursuant to section 1412(b)(7)(C)(iii), in which case the State may specify alternative reporting requirements, as appropriate, until filtration is in place. A public water system that uses a ground water source under the direct influence of surface water and does not provide filtration treatment must report monthly to the State the information specified in this paragraph (a) beginning December 31, 1990, or 6 months after the State determines that the ground water source is under the direct influence of surface water, whichever is later, unless the State has determined that filtration is required in writing pursuant to §1412(b)(7)(C)(iii), in which case the State may specify alternative reporting requirements, as appropriate, until filtration is in place.

(1) Source water quality information must be reported to the State within 10 days after the end of each month the system serves water to the public. Information that must be reported includes:

(i) The cumulative number of months for which results are reported.

(ii) The number of fecal and/or total coliform samples, whichever are analyzed during the month (if a system monitors for both, only fecal coliforms must be reported), the dates of sample collection, and the dates when the turbidity level exceeded 1 NTU.

(iii) The number of samples during the month that had equal to or less than 20/100 ml fecal coliforms and/or equal to or less than 100/100 ml total coliforms, whichever are analyzed.

(iv) The cumulative number of fecal or total coliform samples, whichever are analyzed, during the previous six months the system served water to the public.

(v) The cumulative number of samples that had equal to or less than 20/100 ml fecal coliforms or equal to or less than 100/100 ml total coliforms, whichever are analyzed, during the previous six months the system served water to the public.

(vi) The percentage of samples that had equal to or less than 20/100 ml fecal coliforms or equal to or less than 100/100 ml total coliforms, whichever are analyzed, during the previous six months the system served water to the public.

(vii) The maximum turbidity level measured during the month, the date(s) of occurrence for any measurement(s) which exceeded 5 NTU, and the date(s) the occurrence(s) was reported to the State.

(viii) For the first 12 months of recordkeeping, the dates and cumulative

number of events during which the turbidity exceeded 5 NTU, and after one year of recordkeeping for turbidity measurements, the dates and cumulative number of events during which the turbidity exceeded 5 NTU in the previous 12 months the system served water to the public.

(ix) For the first 120 months of recordkeeping, the dates and cumulative number of events during which the turbidity exceeded 5 NTU, and after 10 years of recordkeeping for turbidity measurements, the dates and cumulative number of events during which the turbidity exceeded 5 NTU in the previous 120 months the system served water to the public.

(2) Disinfection information specified in §141.74(b) must be reported to the State within 10 days after the end of each month the system serves water to the public. Information that must be reported includes:

(i) For each day, the lowest measurement of residual disinfectant concentration in mg/l in water entering the distribution system.

(ii) The date and duration of each period when the residual disinfectant concentration in water entering the distribution system fell below 0.2 mg/l and when the State was notified of the occurrence.

(iii) The daily residual disinfectant concentration(s) (in mg/l) and disinfectant contact time(s) (in minutes) used for calculating the CT value(s).

(iv) If chlorine is used, the daily measurement(s) of pH of disinfected water following each point of chlorine disinfection.

(v) The daily measurement(s) of water temperature in °C following each point of disinfection.

(vi) The daily CTcalc and CTcalc/$CT_{99.9}$ values for each disinfectant measurement or sequence and the sum of all CTcalc/$CT_{99.9}$ values ((CTcalc/$CT_{99.9}$)) before or at the first customer.

(vii) The daily determination of whether disinfection achieves adequate *Giardia* cyst and virus inactivation, i.e., whether (CTcalc/$CT_{99.9}$) is at least 1.0 or, where disinfectants other than chlorine are used, other indicator conditions that the State determines are appropriate, are met.

(viii) The following information on the samples taken in the distribution system in conjunction with total coliform monitoring pursuant to §141.72:

(A) Number of instances where the residual disinfectant concentration is measured;

(B) Number of instances where the residual disinfectant concentration is not measured but heterotrophic bacteria plate count (HPC) is measured;

(C) Number of instances where the residual disinfectant concentration is measured but not detected and no HPC is measured;

(D) Number of instances where the residual disinfectant concentration is detected and where HPC is >500/ml;

(E) Number of instances where the residual disinfectant concentration is not measured and HPC is >500/ml;

(F) For the current and previous month the system served water to the public, the value of ''V'' in the following formula:

$$V = \frac{c + d + e}{a + b} \times 100$$

where:

a=the value in paragraph (a)(2)(viii)(A) of this section,

b=the value in paragraph (a)(2)(viii)(B) of this section,

c=the value in paragraph (a)(2)(viii)(C) of this section,

d=the value in paragraph (a)(2)(viii)(D) of this section, and

e=the value in paragraph (a)(2)(viii)(E) of this section.

(G) If the State determines, based on site-specific considerations, that a system has no means for having a sample transported and analyzed for HPC by a certified laboratory under the requisite time and temperature conditions specified by §141.74(a)(3) and that the system is providing adequate disinfection in the distribution system, the requirements of paragraph (a)(2)(viii) (A)–(F) of this section do not apply to that system.

(ix) A system need not report the data listed in paragraphs (a)(2) (i), and (iii)–(vi) of this section if all data listed in paragraphs (a)(2) (i)–(viii) of this section remain on file at the system, and the State determines that:

(A) The system has submitted to the State all the information required by

paragraphs (a)(2) (i)–(viii) of this section for at least 12 months; and

(B) The State has determined that the system is not required to provide filtration treatment.

(3) No later than ten days after the end of each Federal fiscal year (September 30), each system must provide to the State a report which summarizes its compliance with all watershed control program requirements specified in §141.71(b)(2).

(4) No later than ten days after the end of each Federal fiscal year (September 30), each system must provide to the State a report on the on-site inspection conducted during that year pursuant to §141.71(b)(3), unless the on-site inspection was conducted by the State. If the inspection was conducted by the State, the State must provide a copy of its report to the public water system.

(5)(i) Each system, upon discovering that a waterborne disease outbreak potentially attributable to that water system has occurred, must report that occurrence to the State as soon as possible, but no later than by the end of the next business day.

(ii) If at any time the turbidity exceeds 5 NTU, the system must consult with the primacy agency as soon as practical, but no later than 24 hours after the exceedance is known, in accordance with the public notification requirements under §141.203(b)(3).

(iii) If at any time the residual falls below 0.2 mg/l in the water entering the distribution system, the system must notify the State as soon as possible, but no later than by the end of the next business day. The system also must notify the State by the end of the next business day whether or not the residual was restored to at least 0.2 mg/l within 4 hours.

(b) A public water system that uses a surface water source or a ground water source under the direct influence of surface water and provides filtration treatment must report monthly to the State the information specified in this paragraph (b) beginning June 29, 1993, or when filtration is installed, whichever is later.

(1) Turbidity measurements as required by §141.74(c)(1) must be reported within 10 days after the end of each month the system serves water to the public. Information that must be reported includes:

(i) The total number of filtered water turbidity measurements taken during the month.

(ii) The number and percentage of filtered water turbidity measurements taken during the month which are less than or equal to the turbidity limits specified in §141.73 for the filtration technology being used.

(iii) The date and value of any turbidity measurements taken during the month which exceed 5 NTU.

(2) Disinfection information specified in §141.74(c) must be reported to the State within 10 days after the end of each month the system serves water to the public. Information that must be reported includes:

(i) For each day, the lowest measurement of residual disinfectant concentration in mg/l in water entering the distribution system.

(ii) The date and duration of each period when the residual disinfectant concentration in water entering the distribution system fell below 0.2 mg/l and when the State was notified of the occurrence.

(iii) The following information on the samples taken in the distribution system in conjunction with total coliform monitoring pursuant to §141.72:

(A) Number of instances where the residual disinfectant concentration is measured;

(B) Number of instances where the residual disinfectant concentration is not measured but heterotrophic bacteria plate count (HPC) is measured;

(C) Number of instances where the residual disinfectant concentration is measured but not detected and no HPC is measured;

(D) Number of instances where no residual disinfectant concentration is detected and where HPC is >500/ml;

(E) Number of instances where the residual disinfectant concentration is not measured and HPC is >500/ml;

(F) For the current and previous month the system serves water to the public, the value of ''V'' in the following formula:

$$V = \frac{c + d + e}{a + b} \times 100$$

where:
a=the value in paragraph (b)(2)(iii)(A) of this section,
b=the value in paragraph (b)(2)(iii)(B) of this section,
c=the value in paragraph (b)(2)(iii)(C) of this section,
d=the value in paragraph (b)(2)(iii)(D) of this section, and
e=the value in paragraph (b)(2)(iii)(E) of this section.

(G) If the State determines, based on site-specific considerations, that a system has no means for having a sample transported and analyzed for HPC by a certified laboratory within the requisite time and temperature conditions specified by §141.74(a)(3) and that the system is providing adequate disinfection in the distribution system, the requirements of paragraph (b)(2)(iii) (A)–(F) of this section do not apply.

(iv) A system need not report the data listed in paragraph (b)(2)(i) of this section if all data listed in paragraphs (b)(2) (i)–(iii) of this section remain on file at the system and the State determines that the system has submitted all the information required by paragraphs (b)(2) (i)–(iii) of this section for at least 12 months.

(3)(i) Each system, upon discovering that a waterborne disease outbreak potentially attributable to that water system has occurred, must report that occurrence to the State as soon as possible, but no later than by the end of the next business day.

(ii) If at any time the turbidity exceeds 5 NTU, the system must consult with the primacy agency as soon as practical, but no later than 24 hours after the exceedance is known, in accordance with the public notification requirements under §141.203(b)(3).

(iii) If at any time the residual falls below 0.2 mg/l in the water entering the distribution system, the system must notify the State as soon as possible, but no later than by the end of the next business day. The system also must notify the State by the end of the next business day whether or not the residual was restored to at least 0.2 mg/l within 4 hours.

[54 FR 27527, June 29, 1989, as amended at 65 FR 26022, May 4, 2000]

§141.76 Recycle provisions.

(a) *Applicability.* All subpart H systems that employ conventional filtration or direct filtration treatment and that recycle spent filter backwash water, thickener supernatant, or liquids from dewatering processes must meet the requirements in paragraphs (b) through (d) of this section.

(b) *Reporting.* A system must notify the State in writing by Decemeber 8, 2003, if the system recycles spent filter backwash water, thickener supernatant, or liquids from dewatering processes. This notification must include, at a minimum, the information specified in paragraphs (b)(1) and (2) of this section.

(1) A plant schematic showing the origin of all flows which are recycled (including, but not limited to, spent filter backwash water, thickener supernatant, and liquids from dewatering processes), the hydraulic conveyance used to transport them, and the location where they are re-introduced back into the treatment plant.

(2) Typical recycle flow in gallons per minute (gpm), the highest observed plant flow experienced in the previous year (gpm), design flow for the treatment plant (gpm), and State-approved operating capacity for the plant where the State has made such determinations.

(c) *Treatment technique requirement.* Any system that recycles spent filter backwash water, thickener supernatant, or liquids from dewatering processes must return these flows through the processes of a system's existing conventional or direct filtration system as defined in §141.2 or at an alternate location approved by the State by June 8, 2004. If capital improvements are required to modify the recycle location to meet this requirement, all capital improvements must be completed no later than June 8, 2006.

(d) *Recordkeeping.* The system must collect and retain on file recycle flow information specified in paragraphs (d)(1) through (6) of this section for review and evaluation by the State beginning June 8, 2004.

(1) Copy of the recycle notification and information submitted to the State under paragraph (b) of this section.

Break in sequence

filter number, the turbidity measurement, and the date(s) on which the exceedance occurred. In addition, the system must arrange for the conduct of a comprehensive performance evaluation by the State or a third party approved by the State no later than 30 days following the exceedance and have the evaluation completed and submitted to the State no later than 90 days following the exceedance.

(c) *Additional reporting requirements.* (1) If at any time the turbidity exceeds 1 NTU in representative samples of filtered water in a system using conventional filtration treatment or direct filtration, the system must inform the State as soon as possible, but no later than the end of the next business day.

(2) If at any time the turbidity in representative samples of filtered water exceeds the maximum level set by the State under §141.173(b) for filtration technologies other than conventional filtration treatment, direct filtration, slow sand filtration, or diatomaceous earth filtration, the system must inform the State as soon as possible, but no later than the end of the next business day.

[63 FR 69516, Dec. 16, 1998, as amended at 66 FR 3779, Jan. 16, 2001]

Subpart Q—Public Notification of Drinking Water Violations

SOURCE: 65 FR 26035, May 4, 2000, unless otherwise noted.

§141.201 General public notification requirements.

Public water systems in States with primacy for the public water system supervision (PWSS) program must comply with the requirements in this subpart no later than May 6, 2002 or on the date the State-adopted rule becomes effective, whichever comes first. Public water systems in jurisdictions where EPA directly implements the PWSS program must comply with the requirements in this subpart on October 31, 2000. Prior to these dates, public water systems must continue to comply with the public notice requirements in §141.32 of this part. The term ''primacy agency'' is used in this subpart to refer to either EPA or the State or the Tribe in cases where EPA, the State, or the Tribe exercises primary enforcement responsibility for this subpart.

(a) *Who must give public notice?* Each owner or operator of a public water system (community water systems, non-transient non-community water systems, and transient non-community water systems) must give notice for all violations of national primary drinking water regulations (NPDWR) and for other situations, as listed in Table 1. The term ''NPDWR violations'' is used in this subpart to include violations of the maximum contaminant level (MCL), maximum residual disinfection level (MRDL), treatment technique (TT), monitoring requirements, and testing procedures in this part 141. Appendix A to this subpart identifies the tier assignment for each specific violation or situation requiring a public notice.

TABLE 1 TO §141.201.—VIOLATION CATEGORIES AND OTHER SITUATIONS REQUIRING A PUBLIC NOTICE

(1) NPDWR violations:
- (i) Failure to comply with an applicable maximum contaminant level (MCL) or maximum residual disinfectant level (MRDL).
- (ii) Failure to comply with a prescribed treatment technique (TT).
- (iii) Failure to perform water quality monitoring, as required by the drinking water regulations.
- (iv) Failure to comply with testing procedures as prescribed by a drinking water regulation.

(2) Variance and exemptions under sections 1415 and 1416 of SDWA:
- (i) Operation under a variance or an exemption.
- (ii) Failure to comply with the requirements of any schedule that has been set under a variance or exemption.

(3) Special public notices:
- (i) Occurrence of a waterborne disease outbreak or other waterborne emergency.
- (ii) Exceedance of the nitrate MCL by non-community water systems (NCWS), where granted permission by the primacy agency under 141.11(d) of this part.

TABLE 1 TO § 141.201.—VIOLATION CATEGORIES AND OTHER SITUATIONS REQUIRING A PUBLIC NOTICE—Continued

(iii) Exceedance of the secondary maximum contaminant level (SMCL) for fluoride.
(iv) Availability of unregulated contaminant monitoring data.
(v) Other violations and situations determined by the primacy agency to require a public notice under this subpart, not already listed in Appendix A.

(b) *What type of public notice is required for each violation or situation?* Public notice requirements are divided into three tiers, to take into account the seriousness of the violation or situation and of any potential adverse health effects that may be involved. The public notice requirements for each violation or situation listed in Table 1 of this section are determined by the tier to which it is assigned. Table 2 of this section provides the definition of each tier. Appendix A of this part identifies the tier assignment for each specific violation or situation.

TABLE 2 TO § 141.201.—DEFINITION OF PUBLIC NOTICE TIERS

(1) *Tier 1 public notice*—required for NPDWR violations and situations with significant potential to have serious adverse effects on human health as a result of short-term exposure.
(2) *Tier 2 public notice*—required for all other NPDWR violations and situations with potential to have serious adverse effects on human health.
(3) *Tier 3 public notice*—required for all other NPDWR violations and situations not included in Tier 1 and Tier 2.

(c) *Who must be notified?*

(1) Each public water system must provide public notice to persons served by the water system, in accordance with this subpart. Public water systems that sell or otherwise provide drinking water to other public water systems (i.e., to consecutive systems) are required to give public notice to the owner or operator of the consecutive system; the consecutive system is responsible for providing public notice to the persons it serves.

(2) If a public water system has a violation in a portion of the distribution system that is physically or hydraulically isolated from other parts of the distribution system, the primacy agency may allow the system to limit distribution of the public notice to only persons served by that portion of the system which is out of compliance. Permission by the primacy agency for limiting distribution of the notice must be granted in writing.

(3) A copy of the notice must also be sent to the primacy agency, in accordance with the requirements under § 141.31(d).

§ 141.202 Tier 1 Public Notice—Form, manner, and frequency of notice.

(a) *Which violations or situations require a Tier 1 public notice?* Table 1 of this section lists the violation categories and other situations requiring a Tier 1 public notice. Appendix A to this subpart identifies the tier assignment for each specific violation or situation.

TABLE 1 TO § 141.202.—VIOLATION CATEGORIES AND OTHER SITUATIONS REQUIRING A TIER 1 PUBLIC NOTICE

(1) Violation of the MCL for total coliforms when fecal coliform or E. coli are present in the water distribution system (as specified in § 141.63(b)), or when the water system fails to test for fecal coliforms or E. coli when any repeat sample tests positive for coliform (as specified in § 141.21(e));
(2) Violation of the MCL for nitrate, nitrite, or total nitrate and nitrite, as defined in § 141.62, or when the water system fails to take a confirmation sample within 24 hours of the system's receipt of the first sample showing an exceedance of the nitrate or nitrite MCL, as specified in § 141.23(f)(2);
(3) Exceedance of the nitrate MCL by noncommunity water systems, where permitted to exceed the MCL by the primacy agency under § 141.11(d), as required under § 141.209;

TABLE 1 TO § 141.202.—VIOLATION CATEGORIES AND OTHER SITUATIONS REQUIRING A TIER 1 PUBLIC NOTICE—Continued

(4) Violation of the MRDL for chlorine dioxide, as defined in § 141.65(a), when one or more samples taken in the distribution system the day following an exceedance of the MRDL at the entrance of the distribution system exceed the MRDL, or when the water system does not take the required samples in the distribution system, as specified in § 141.133(c)(2)(i);
(5) Violation of the turbidity MCL under § 141.13(b), where the primacy agency determines after consultation that a Tier 1 notice is required or where consultation does not take place within 24 hours after the system learns of the violation;
(6) Violation of the Surface Water Treatment Rule (SWTR), Interim Enhanced Surface Water Treatment Rule (IESWTR) or Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) treatment technique requirement resulting from a single exceedance of the maximum allowable turbidity limit (as identified in Appendix A), where the primacy agency determines after consultation that a Tier 1 notice is required or where consultation does not take place within 24 hours after the system learns of the violation;
(7) Occurrence of a waterborne disease outbreak, as defined in § 141.2, or other waterborne emergency (such as a failure or significant interruption in key water treatment processes, a natural disaster that disrupts the water supply or distribution system, or a chemical spill or unexpected loading of possible pathogens into the source water that significantly increases the potential for drinking water contamination);
(8) Other violations or situations with significant potential to have serious adverse effects on human health as a result of short-term exposure, as determined by the primacy agency either in its regulations or on a case-by-case basis.

(b) *When is the Tier 1 public notice to be provided?* What additional steps are required? Public water systems must:

(1) Provide a public notice as soon as practical but no later than 24 hours after the system learns of the violation;

(2) Initiate consultation with the primacy agency as soon as practical, but no later than 24 hours after the public water system learns of the violation or situation, to determine additional public notice requirements; and

(3) Comply with any additional public notification requirements (including any repeat notices or direction on the duration of the posted notices) that are established as a result of the consultation with the primacy agency. Such requirements may include the timing, form, manner, frequency, and content of repeat notices (if any) and other actions designed to reach all persons served.

(c) *What is the form and manner of the public notice?* Public water systems must provide the notice within 24 hours in a form and manner reasonably calculated to reach all persons served. The form and manner used by the public water system are to fit the specific situation, but must be designed to reach residential, transient, and non-transient users of the water system. In order to reach all persons served, water systems are to use, at a minimum, one or more of the following forms of delivery:

(1) Appropriate broadcast media (such as radio and television);

(2) Posting of the notice in conspicuous locations throughout the area served by the water system;

(3) Hand delivery of the notice to persons served by the water system; or

(4) Another delivery method approved in writing by the primacy agency.

[65 FR 26035, May 4, 2000, as amended at 67 FR 1836, Jan. 14, 2002]

§ 141.203 Tier 2 Public Notice—Form, manner, and frequency of notice.

(a) *Which violations or situations require a Tier 2 public notice?* Table 1 of this section lists the violation categories and other situations requiring a Tier 2 public notice. Appendix A to this subpart identifies the tier assignment for each specific violation or situation.

TABLE 1 TO § 141.203.—VIOLATION CATEGORIES AND OTHER SITUATIONS REQUIRING A TIER 2 PUBLIC NOTICE

(1) All violations of the MCL, MRDL, and treatment technique requirements, except where a Tier 1 notice is required under § 141.202(a) or where the primacy agency determines that a Tier 1 notice is required;
(2) Violations of the monitoring and testing procedure requirements, where the primacy agency determines that a Tier 2 rather than a Tier 3 public notice is required, taking into account potential health impacts and persistence of the violation; and
(3) Failure to comply with the terms and conditions of any variance or exemption in place.

(b) *When is the Tier 2 public notice to be provided?*

(1) Public water systems must provide the public notice as soon as practical, but no later than 30 days after the system learns of the violation. If the public notice is posted, the notice must remain in place for as long as the violation or situation persists, but in no case for less than seven days, even if the violation or situation is resolved. The primacy agency may, in appropriate circumstances, allow additional time for the initial notice of up to three months from the date the system learns of the violation. It is not appropriate for the primacy agency to grant an extension to the 30-day deadline for any unresolved violation or to allow across-the-board extensions by rule or policy for other violations or situations requiring a Tier 2 public notice. Extensions granted by the primacy agency must be in writing.

(2) The public water system must repeat the notice every three months as long as the violation or situation persists, unless the primacy agency determines that appropriate circumstances warrant a different repeat notice frequency. In no circumstance may the repeat notice be given less frequently than once per year. It is not appropriate for the primacy agency to allow less frequent repeat notice for an MCL violation under the Total Coliform Rule or a treatment technique violation under the Surface Water Treatment Rule or Interim Enhanced Surface Water Treatment Rule. It is also not appropriate for the primacy agency to allow through its rules or policies across-the-board reductions in the repeat notice frequency for other ongoing violations requiring a Tier 2 repeat notice. Primacy agency determinations allowing repeat notices to be given less frequently than once every three months must be in writing.

(3) For the turbidity violations specified in this paragraph, public water systems must consult with the primacy agency as soon as practical but no later than 24 hours after the public water system learns of the violation, to determine whether a Tier 1 public notice under § 141.202(a) is required to protect public health. When consultation does not take place within the 24-hour period, the water system must distribute a Tier 1 notice of the violation within the next 24 hours (*i.e.*, no later than 48 hours after the system learns of the violation), following the requirements under § 141.202(b) and (c). Consultation with the primacy agency is required for:

(i) Violation of the turbidity MCL under § 141.13(b); or

(ii) Violation of the SWTR, IESWTR or LT1ESWTR treatment technique requirement resulting from a single exceedance of the maximum allowable turbidity limit.

(c) *What is the form and manner of the Tier 2 public notice?* Public water systems must provide the initial public notice and any repeat notices in a form and manner that is reasonably calculated to reach persons served in the required time period. The form and manner of the public notice may vary based on the specific situation and type of water system, but it must at a minimum meet the following requirements:

(1) Unless directed otherwise by the primacy agency in writing, community water systems must provide notice by:

(i) Mail or other direct delivery to each customer receiving a bill and to other service connections to which water is delivered by the public water system; and

(ii) Any other method reasonably calculated to reach other persons regularly served by the system, if they would not normally be reached by the notice required in paragraph (c)(1)(i) of

this section. Such persons may include those who do not pay water bills or do not have service connection addresses (*e.g.*, house renters, apartment dwellers, university students, nursing home patients, prison inmates, etc.). Other methods may include: Publication in a local newspaper; delivery of multiple copies for distribution by customers that provide their drinking water to others (*e.g.*, apartment building owners or large private employers); posting in public places served by the system or on the Internet; or delivery to community organizations.

(2) Unless directed otherwise by the primacy agency in writing, non-community water systems must provide notice by:

(i) Posting the notice in conspicuous locations throughout the distribution system frequented by persons served by the system, or by mail or direct delivery to each customer and service connection (where known); and

(ii) Any other method reasonably calculated to reach other persons served by the system if they would not normally be reached by the notice required in paragraph (c)(2)(i) of this section. Such persons may include those served who may not see a posted notice because the posted notice is not in a location they routinely pass by. Other methods may include: Publication in a local newspaper or newsletter distributed to customers; use of E-mail to notify employees or students; or, delivery of multiple copies in central locations (*e.g.*, community centers).

[65 FR 26035, May 4, 2000, as amended at 67 FR 1836, Jan. 14, 2002]

§ 141.204 Tier 3 Public Notice—Form, manner, and frequency of notice.

(a) *Which violations or situations require a Tier 3 public notice?* Table 1 of this section lists the violation categories and other situations requiring a Tier 3 public notice. Appendix A to this subpart identifies the tier assignment for each specific violation or situation.

TABLE 1 TO § 141.204.—VIOLATION CATEGORIES AND OTHER SITUATIONS REQUIRING A TIER 3 PUBLIC NOTICE

(1) Monitoring violations under 40 CFR part 141, except where a Tier 1 notice is required under § 141.202(a) or where the primacy agency determines that a Tier 2 notice is required;
(2) Failure to comply with a testing procedure established in 40 CFR part 141, except where a Tier 1 notice is required under § 141.202(a)) or where the primacy agency determines that a Tier 2 notice is required;
(3) Operation under a variance granted under Section 1415 or an exemption granted under Section 1416 of the Safe Drinking Water Act;
(4) Availability of unregulated contaminant monitoring results, as required under § 141.207; and
(5) Exceedance of the fluoride secondary maximum contaminant level (SMCL), as required under § 141.208.

(b) *When is the Tier 3 public notice to be provided?*

(1) Public water systems must provide the public notice not later than one year after the public water system learns of the violation or situation or begins operating under a variance or exemption. Following the initial notice, the public water system must repeat the notice annually for as long as the violation, variance, exemption, or other situation persists. If the public notice is posted, the notice must remain in place for as long as the violation, variance, exemption, or other situation persists, but in no case less than seven days (even if the violation or situation is resolved).

(2) Instead of individual Tier 3 public notices, a public water system may use an annual report detailing all violations and situations that occurred during the previous twelve months, as long as the timing requirements of paragraph (b)(1) of this section are met.

(c) *What is the form and manner of the Tier 3 public notice?* Public water systems must provide the initial notice and any repeat notices in a form and manner that is reasonably calculated to reach persons served in the required time period. The form and manner of